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LUNAR ORBITAL TECHNIQUE (U)

FOR PERFORMING

THE LUNAR MISSION

GROUP-4

(NASA-TM-X-66758) LUNAR ORBITAL TECHNIQUE FOR PERFORMING THE LUNAR MISSION (NASA) 61 p

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Unclas
00/12 11506

~~GROUP Downgraded at 3 year intervals; declassified after 12 years~~

FF No. 602 [redacted] (CATEGORY) NASA

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LUNAR ORBITAL TECHNIQUE FOR PERFORMING THE LUNAR MISSION

PREPARED BY:

MANNED SPACECRAFT CENTER
Houston, Texas

APRIL, 1962

[redacted]

INTRODUCTION

The Apollo Spacecraft is being designed, developed and qualified for the ultimate mission of lunar landing and return. Several techniques have been investigated for performing the lunar-landing and lunar-launch phase of the mission. The Manned Spacecraft Center has studied a Lunar Excursion Module (LEM) System which is designed for direct earth-launch and a lunar orbit rendezvous technique for performing the lunar-landing and lunar-launch phase.

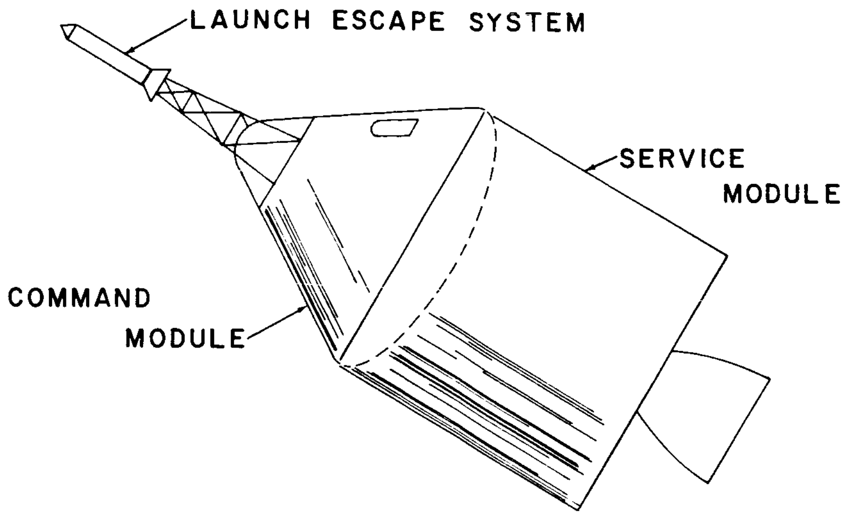
The lunar orbit rendezvous technique involves the injection of the complete Apollo Spacecraft into a translunar trajectory using one Saturn C-5 Launch Vehicle. The Spacecraft for this mode is composed of the Command, Service and Lunar Excursion Modules. After injection and prior to the first midcourse correction, the Lunar Excursion Module is docked to the Command Module. The Service Module propulsion system is used for performing the midcourse maneuvers and for placing the Spacecraft into a lunar orbit. In lunar orbit the Lunar Excursion Module with two crew members aboard separates from the Command Module and descends to a lunar landing. The third crew member remains in the Command Module in lunar orbit. The Lunar Excursion Module crew performs their mission goal tasks and return to lunar orbit with their records and specimens. The Lunar Excursion Module crew performs a rendezvous and docking maneuver with the Command Module. The crew and payload transfer to the Command Module and the Command Module, with or without the Lunar Excursion Module, is injected into a transearth trajectory by the Service Module propulsion system.

The following material is a summary of the study. The MIT Instrumentation Laboratory performed the Navigation and Guidance System phase of the study. The Systems Integration study was performed by NAA Space and Information Systems Division.

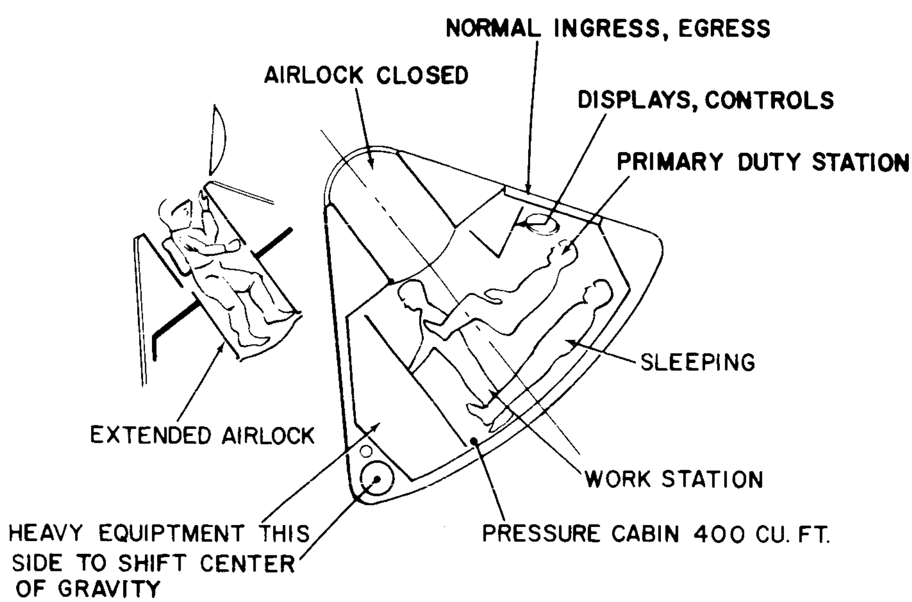
TABLE OF CONTENTS

COMMAND AND SERVICE MODULE

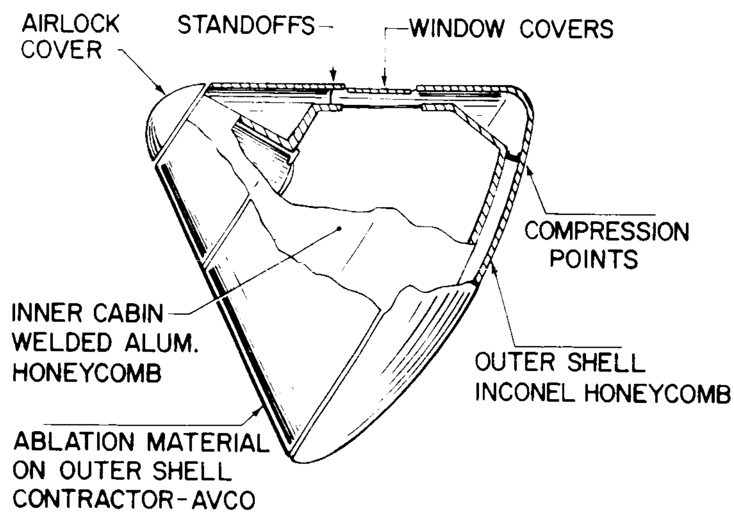
APOLLO SPACECRAFT



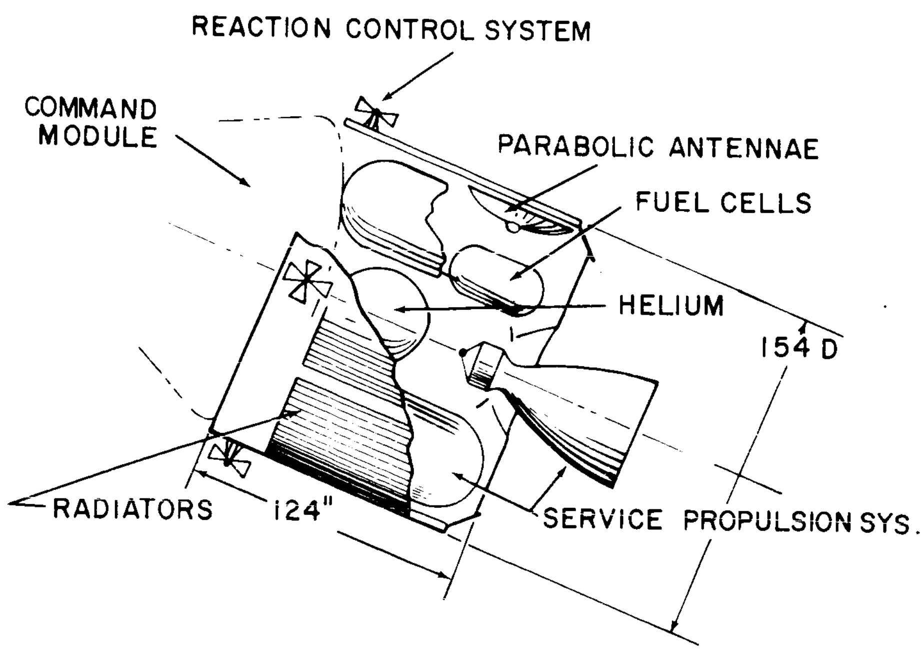
COMMAND MODULE



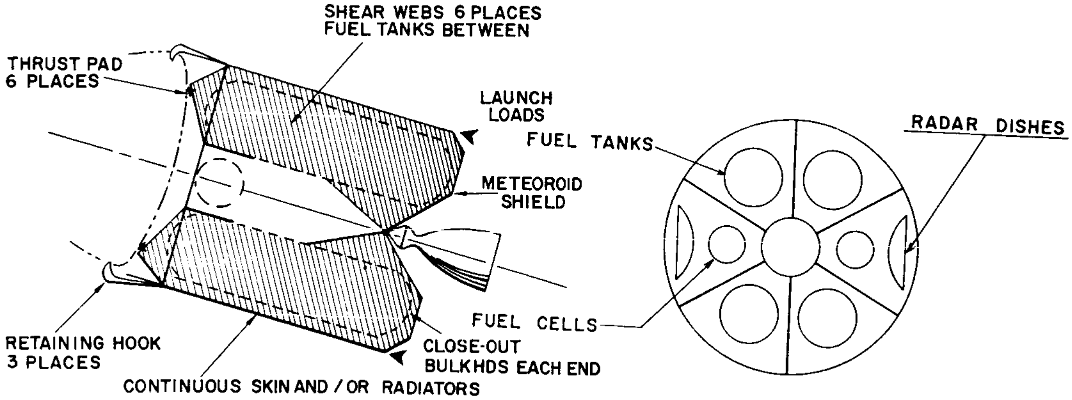
STRUCTURAL SYSTEM C/M
(INCLUDE THERMAL PROTECTION)



SERVICE MODULE



STRUCTURAL SYSTEM, S/M

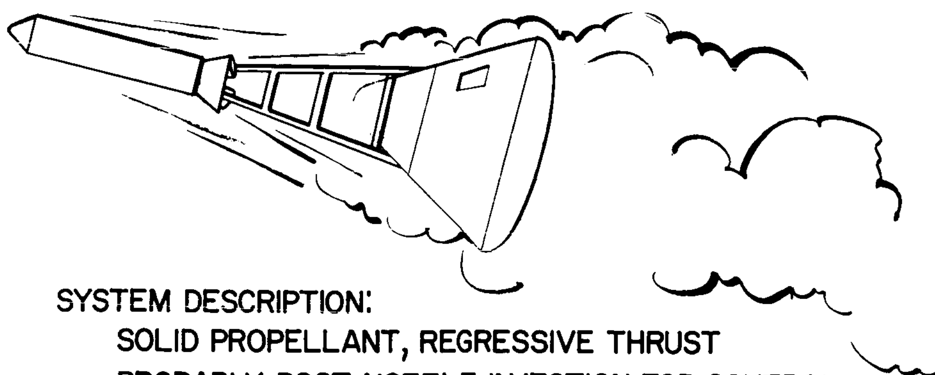


LAUNCH ESCAPE SYSTEM

DUTIES:

LIFTS C/M 5000 FT ABOVE PAD

SEPARATES C/M FROM LAUNCH VEHICLE 125 FT IN FIRST SECOND AT MAX Q



SYSTEM DESCRIPTION:

SOLID PROPELLANT, REGRESSIVE THRUST

PROBABLY POST-NOZZLE INJECTION FOR CONTROL

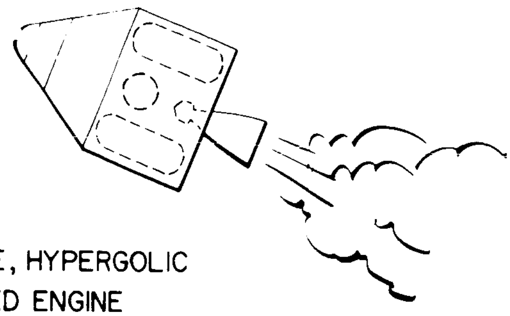
CONTRACTOR-LOCKHEED

SEPARATION MOTOR CONTRACTOR-THIOKOL

SERVICE PROPULSION SYSTEM

DUTIES:

- EARTH-ORBIT RETROGRADE
- MID-COURSE VELOCITY CHANGES
- EXTRA ATMOSPHERE ABORT
- LUNAR ORBIT (PHASE B)
- LUNAR LAUNCH



SYSTEM DESCRIPTION:

- EARTH STORABLE, HYPERGOLIC
- SINGLE, GIMBALLED ENGINE
- ABLATION COOLED
- PRESSURE FED
- CONTRACTOR-AEROJET

REACTION CONTROL SYSTEM

SERVICE MODULE:

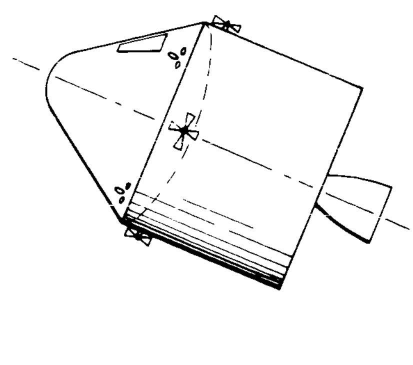
- SPACECRAFT ATTITUDE REACTION CONTROL
- ULLAGE DUTY FOR SERVICE PROP. SYST.
- MINOR MID-COURSE CORRECTION
- DOCKING

COMMAND MODULE:

- 3-AXIS ENTRY CONTROL
- LANDING ROLL CONTROL

SYSTEM DESCRIPTION:

- EARTH STORABLE, HYPERGOLIC
- PULSE MODULATED, SEMI-RADIATIVE
- POSITIVE EXPULSION
- CONTRACTOR - MARQUARDT



ENVIRONMENTAL CONTROL

ATMOSPHERIC COMPOSITION:

- OXYGEN-NITROGEN
- 7.0 PSIA CABIN, 3.5 PSIA SUIT
- USES FUEL CELL OXYGEN
- 3-PRESSURIZATION + 18-AIRLOCK OPER.+ LEAKAGE

TEMPERATURE AND HUMIDITY:

- SQUEEZABLE SPONGE FOR WATER SEPARTION
- WATER EVAPORATOR DURING LAUNCH, ENTRY
- VITAL EQUIPMENT USES ACTIVE COOLING

SCAVENGING:

- LITHIUM-HYDROXIDE CO_2 REMOVAL
- CHARCOAL AND CATALYTIC BURNER FOR NOXIOUS GASES.
- INTERMITTANT WASTE JETTISONED

COMMUNICATIONS AND INSTRUMENTATION

COMMUNICATIONS:

- TRANSMISSION OF DIGITAL PCM ON PROGRAMMED BASIS (DATA PLUS VOICE OR DATA PLUS TV)
- CONTINUOUS RECEPTION OF ANALOGUE VOICE EXCEPT ON FAR SIDE OF MOON
- VHF FOR NEAR-EARTH PHASES
- UHF/DSIF IN DEEP SPACE
- UHF COMMAND EQUIPMENT MAY BE LIMITED TO LAUNCH VEHICLE
- UHF, HF, AND VHF RECOVERY AIDS
- MAJOR CONTRACTOR – COLLINS RADIO

INSTRUMENTATIONS:

- OPERATIONAL EQUIPMENT – BY NAA
- RESEARCH AND DEVELOPMENT – BY MSC

ELECTRICAL POWER SYSTEM

REQUIREMENTS:

•NOMIMAL	2.0 KW
•EMERGENCY	0.6 KW
•ENTRY	1.0 KW

SYSTEM DESCRIPTION:

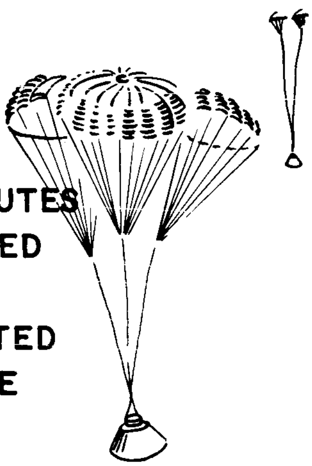
- OXYGEN-HYDROGEN FUEL CELLS
- 3 UNITS, SIZED FOR 2 OUT OF 3
- CONTRACTOR-PRATT & WHITNEY
- WATER-GLYCOL - RADIATOR COOLING
- WATER SAVED FOR DRINKING, COOLING
- SILVER-ZINC PRIMARY BATTERIES

EARTH LANDING SYSTEM

DUTIES:

- STABILIZES
- REDUCES IMPACT VELOCITY TO 30 FPS

SYSTEM DESCRIPTION:

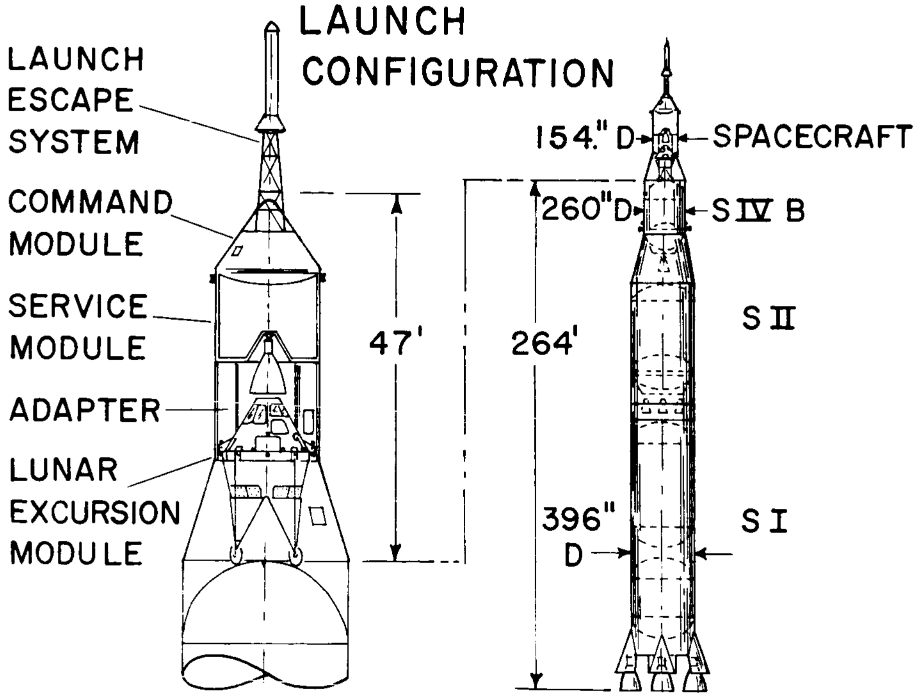


- FIST RIBBON DROGUES
- 93 FT. RINGSAIL MAIN CHUTES
- SIMULTANEOUSLY DEPLOYED
- SIZED FOR 2 OUT OF 3
- CANTED C/M, ROLL ORIENTED
- CONTRACTOR-RADIOPLANE

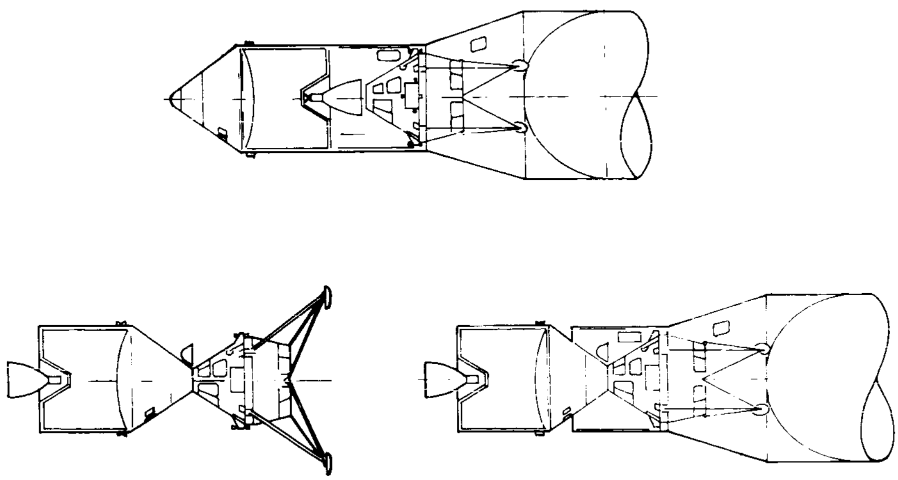
SPECIAL PROVISION:

- MUST BE COMPATIBLE WITH PARAWING

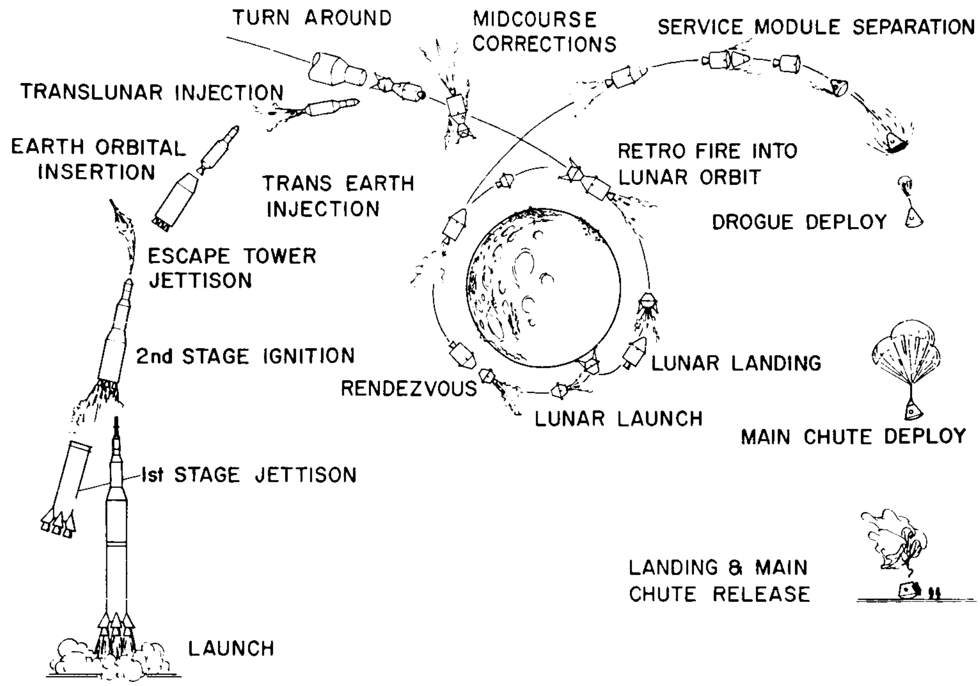
MISSION AND SPACE VEHICLE CONCEPT



SPACE FLIGHT CONFIGURATIONS



MISSION SEQUENCE CONFIGURATIONS



LUNAR EXCURSION MODULE GUIDE LINES

2 MEN AND PAYLOAD LAND ON THE MOON

STAY TIME IS NOMINALLY 24 HOURS

CONTINGENCY IS 24 HOURS

EXPLORATION NEAR LANDING SITE

LAND AT VARIOUS DESIGNATED POINTS

CAPABILITY FOR ABORT TO LUNAR RENDEZVOUS

LEM. TO HAVE ONBOARD COMMAND

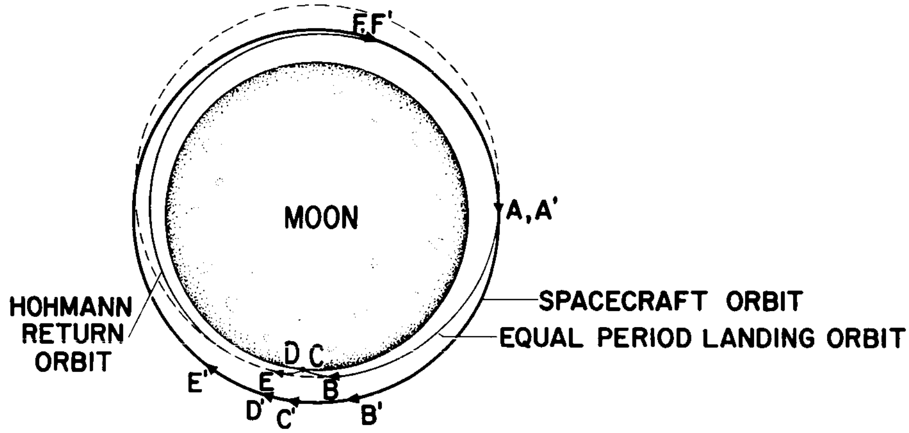
CABIN ENVIRONMENT TO ALLOW OPEN FACE PLATE

BASIC ATTRACTIVE FEATURES OF LUNAR RENDEZVOUS

- HIGH PAYLOAD EFFICIENCY
- MINIMUM CONSTRAINT ON DESIGN OF LUNAR LANDER
- SMALLEST SIZE FOR LUNAR LANDER

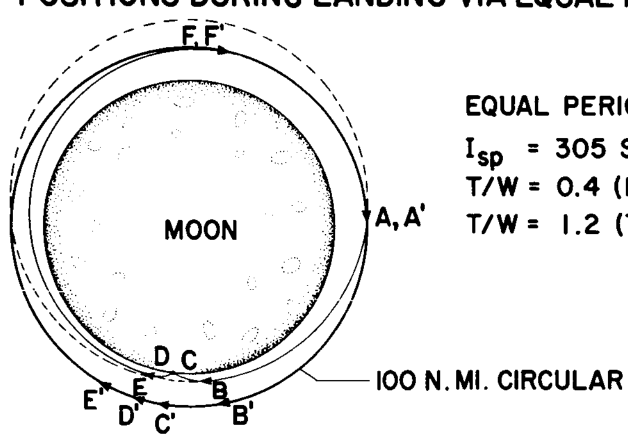
LUNAR ORBITAL OPERATIONS

LUNAR LANDING TECHNIQUE VIA EQUAL PERIOD TRANSFER



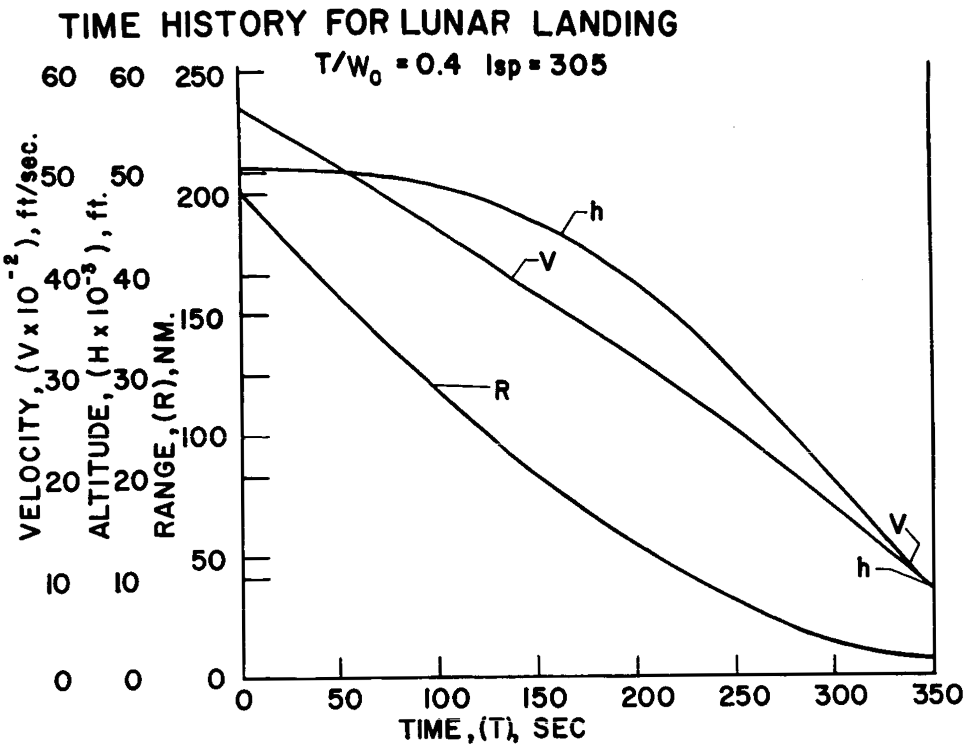
A SEPARATION OF LUNAR LANDER FROM SPACECRAFT
B INITIATION OF LANDING MANEUVER
C START OF HOVER
D ABORT FROM HOVER OR TAKEOFF FROM LUNAR SURFACE
E INSERTION INTO RETURN ORBIT
F RENDEZVOUS OF SPACECRAFT AND LUNAR LANDER

POSITIONS DURING LANDING VIA EQUAL PERIOD TRANSFER

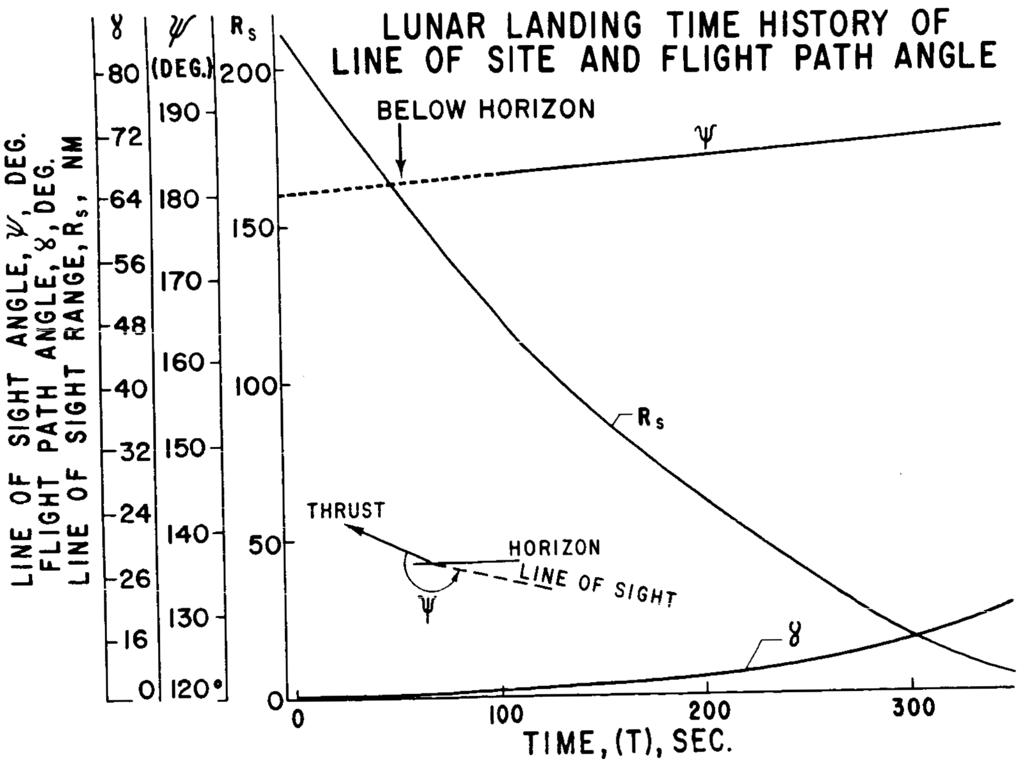


EQUAL PERIOD TRANSFER
I_{sp} = 305 SEC.
T/W = 0.4 (LANDING)
T/W = 1.2 (TAKE-OFF AND ABORT)

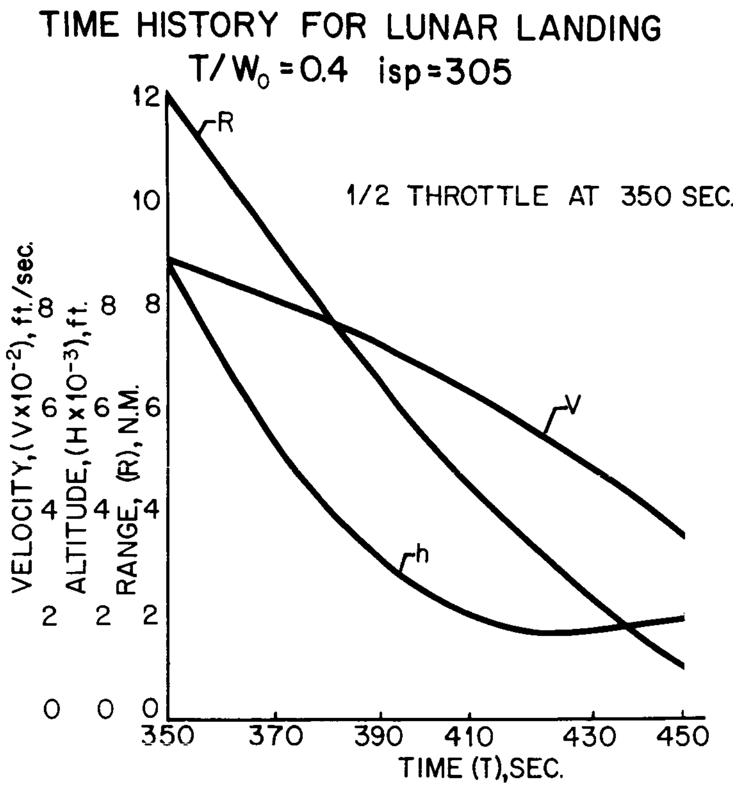
EVENT	TIME MIN.	ANGULAR POSITION, DEG.	
		LUNAR LANDER	SPACECRAFT
A	0	0	0
B	29.78	95.07	84.94
C	36.62	107.76	104.44
D	41.02	107.76	116.99
E	42.95	110.69	122.49
F	101.91	290.69	290.69

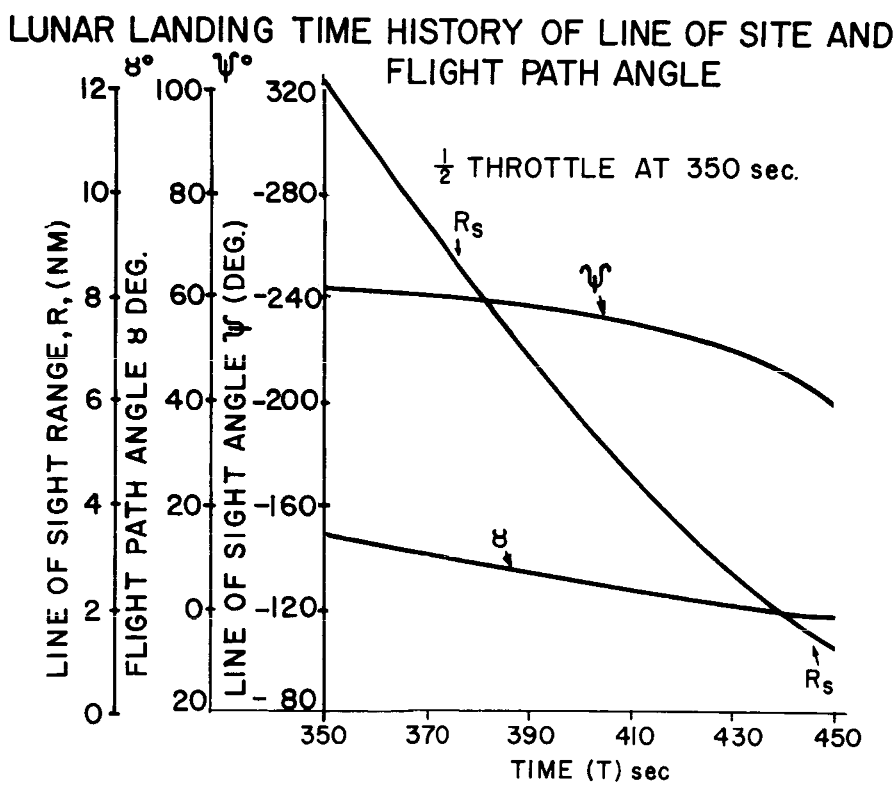


TIME HISTORY FOR LUNAR LANDING
T/W0 = 0.4 Isp = 305
VELOCITY, (V x 10^-2), ft/sec.
ALTITUDE, (H x 10^-3), ft.
RANGE, (R), NM.
TIME, (T), SEC
h
V
R

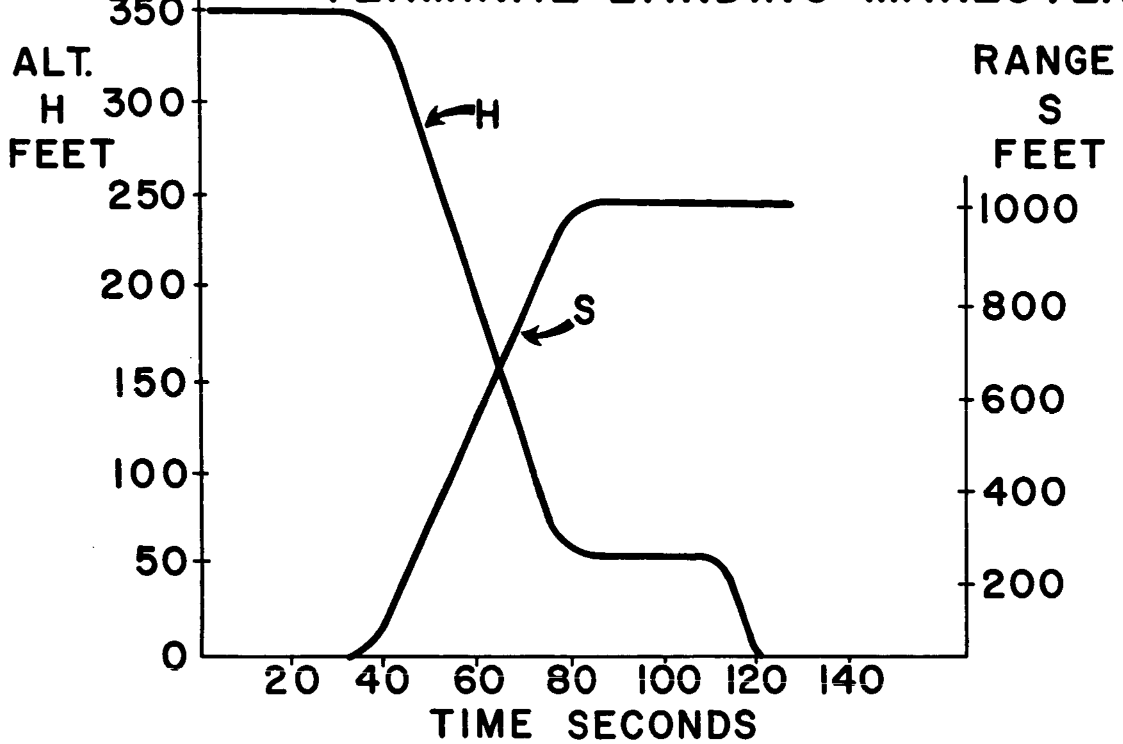


LUNAR LANDING TIME HISTORY OF
LINE OF SITE AND FLIGHT PATH ANGLE
BELOW HORIZON
LINE OF SIGHT ANGLE, ψ, DEG.
FLIGHT PATH ANGLE, γ, DEG.
LINE OF SIGHT RANGE, Rs, NM
(DEG.)
THRUST
HORIZON
LINE OF SIGHT
TIME, (T), SEC.

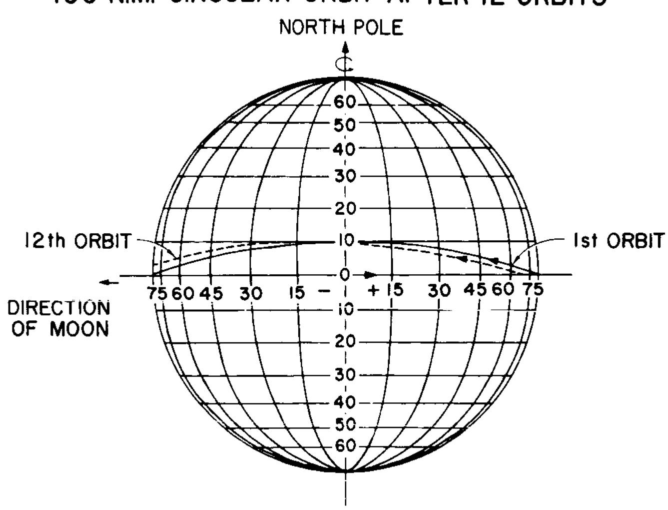

TIME HISTORY FOR LUNAR LANDING
T/W0 = 0.4 isp = 305
1/2 THROTTLE AT 350 SEC.
R
V
h
VELOCITY, (V x 10^-2), ft./sec.
ALTITUDE, (H x 10^-3), ft.
RANGE, (R), N.M.
TIME (T), SEC.
350
370
390
410
430
450


LUNAR LANDING TIME HISTORY OF LINE OF SITE AND FLIGHT PATH ANGLE
½ THROTTLE AT 350 sec.
Rs
ψ
γ
LINE OF SIGHT RANGE, R, (NM)
FLIGHT PATH ANGLE γ DEG.
LINE OF SIGHT ANGLE ψ (DEG.)
TIME (T) sec
350
370
390
410
430
450

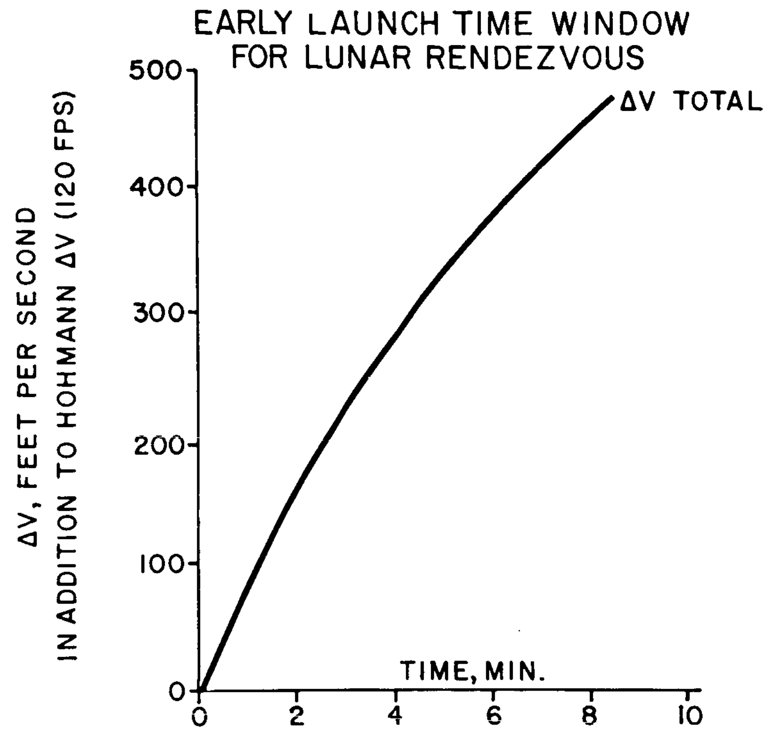
LUNAR EXCURSION MODULE TERMINAL LANDING MANEUVER

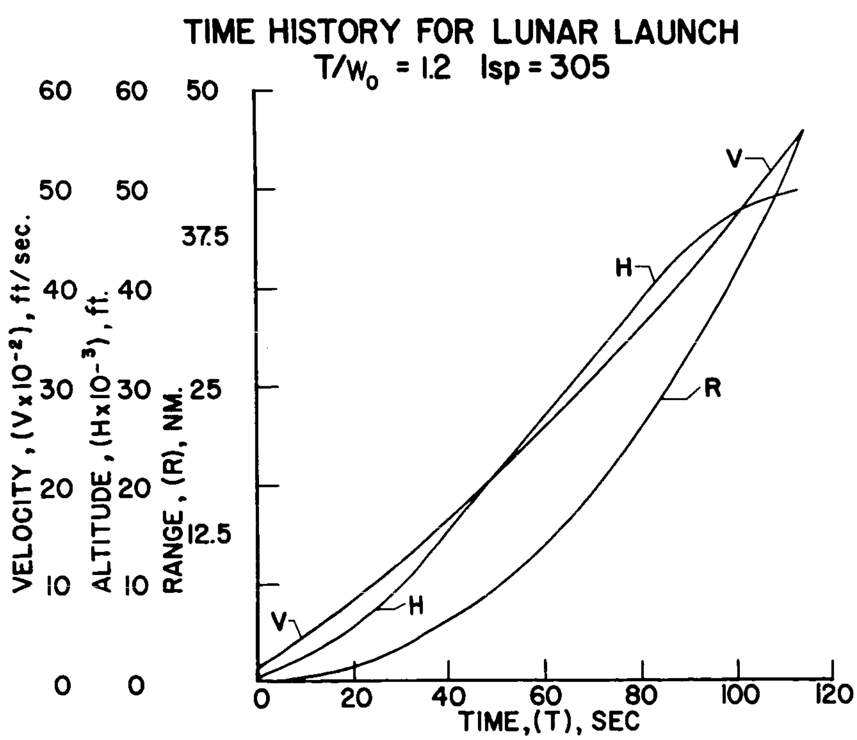


PERTURBATIONS OF A 10° INCLINED, 100 N.M. CIRCULAR ORBIT AFTER 12 ORBITS

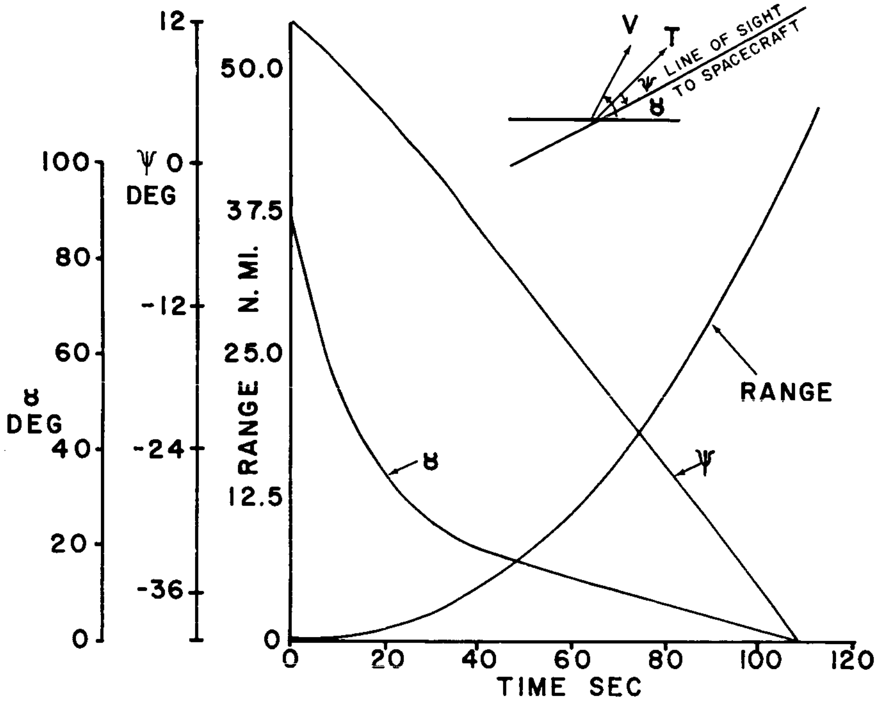


	INCLINATION (DEG.)	ECCENTRICITY	PERICYNTHION (N.M.)	APOCYNTHION (N.M.)	PERIOD (HR.)	INERTIAL ASC.NODE (DEG.)	ASC. NODE MOON ROTATION (DEG.)
INITIAL VALUE	10.0000	0	1038.48	1038.48	2.1043	0	90.0
CHANGE AFTER 12 ORBITS	0.0078	.000048	-0.05	0.03	-0.0013	-0.885	-15.15
MAX. CHANGE	0.0078	.000048	-0.74	-1.2	-0.0013	-0.885	-15.15


EARLY LAUNCH TIME WINDOW
FOR LUNAR RENDEZVOUS
ΔV TOTAL
ΔV, FEET PER SECOND
IN ADDITION TO HOHMANN ΔV (120 FPS)
TIME, MIN.
500
400
300
200
100
0
0
2
4
6
8
10


TIME HISTORY FOR LUNAR LAUNCH
T/W0 = 1.2 Isp = 305
VELOCITY, (Vx10^-2), ft/sec.
ALTITUDE, (Hx10^-3), ft.
RANGE, (R), NM.
60 60 50
50 50
37.5
40 40
30 30 25
20 20
12.5
10 10
0 0
V
H
R
0
20
40
60
80
100
120
TIME, (T), SEC

LUNAR LAUNCH TIME HISTORY
OF LINE OF SIGHT & FLIGHT PATH ANGLE

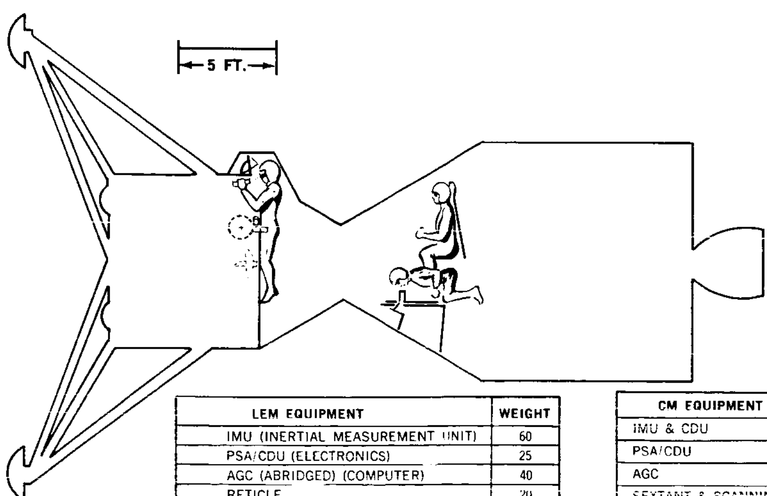


NAVIGATION AND GUIDANCE SYSTEM

DESIGN APPROACH

1. PROVIDE CAPABILITY TO LAND WITH ONLY ONBOARD SYSTEMS
2. PROVIDE CAPABILITY TO LAND WITH AIDE OF LUNAR SURFACE BEACON.
3. ATTEMPT TO IMPROVE FUEL RESERVE OR PAYLOAD CAPABILITY BY MEANS OF GUIDANCE PRECISION.
4. FAVOR USE OF EQUIPMENT INTERCHANGEABLE WITH COMMAND MODULE EQUIPMENT
5. PROVIDE ULTIMATE BACK-UP THROUGH MANUAL CONTROL USING RUDIMENTARY COMPONENTS AND ASSISTANCE FROM MOTHER SPACECRAFT

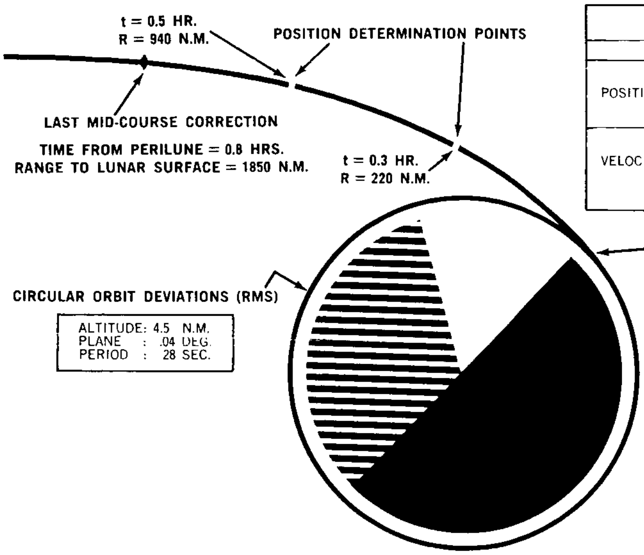
GUIDANCE EQUIPMENT



LEM EQUIPMENT	WEIGHT
IMU (INERTIAL MEASUREMENT UNIT)	60
PSA/CDU (ELECTRONICS)	25
AGC (ABRIDGED) (COMPUTER)	40
RETICLE	20
ALIGNMENT TELESCOPE	15
TRACKING RADAR	55
ALTIMETER	10
CONTROLS & DISPLAYS	20
BACK-UP INERTIAL COMPONENTS	20
CABLING	10
TOTAL	275

CM EQUIPMENT	WEIGHT
IMU & CDU	60
PSA/CDU	26
AGC	100
SEXTANT & SCANNING TELESCOPE	40
TRANSPONDER	10
CABLING	11
MAP & VISUAL DISPLAY	10
DISPLAY & CONTROLS	33
TOTAL	290

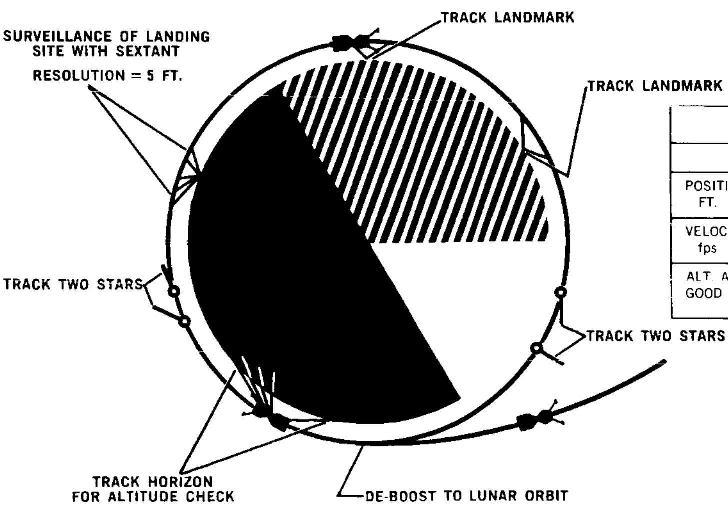
LUNAR ORBIT INJECTION



INITIAL ERRORS (RMS)			
		UNCERTAINTY	DEVIATION
POSITION	ALTITUDE	0.8 N.M.	2.5 N.M.
	RANGE	0.4 N.M.	3.5 N.M.
	TRACK	0.4 N.M.	0.5 N.M.
VELOCITY	ALTITUDE	5 fps	105 fps
	RANGE	1 fps	37 fps
	TRACK	1 fps	2 fps

POST-INJECTION ERRORS (RMS)		
		UNCERTAINTY
POSITION	ALTITUDE	0.85 N.M.
	RANGE	0.5 N.M.
	TRACK	0.5 N.M.
VELOCITY	ALTITUDE	5.3 fps
	RANGE	2.1 fps
	TRACK	2.1 fps

LUNAR ORBIT DETERMINATION

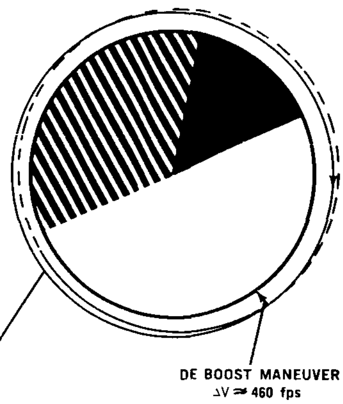


ORBIT UNCERTAINTIES			
	ALT.	RANGE	TRACK
POSITION FT.	1500′	1500	1500
VELOCITY fps	2	2	2
ALT. ABOVE TERRAIN FEATURE GOOD TO 300′			

L.E.M. DE-BOOST AND COAST TO PERILUNE

DE-BOOST MANEUVER

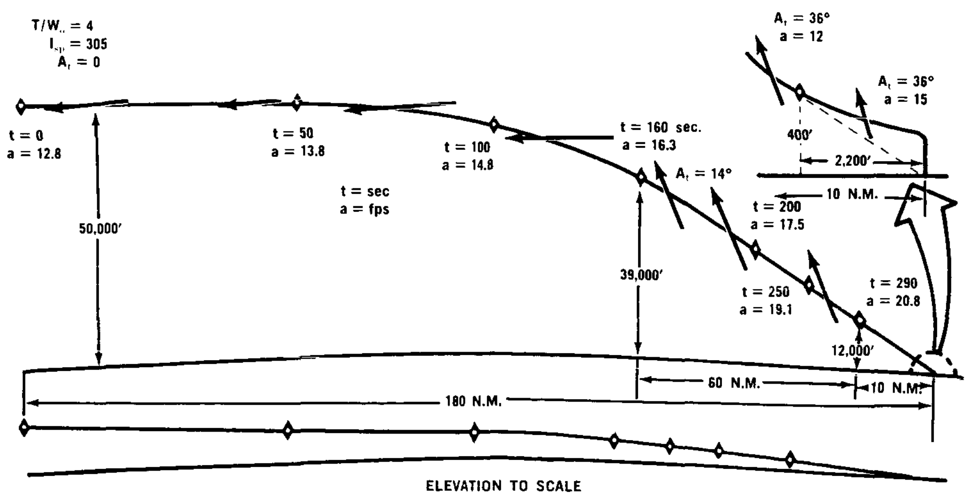
DE-BOOST UNCERTAINTIES (RMS) RELATIVE TO LUNAR ORBIT		
	POSITION	VELOCITY
RANGE	< 50 ft	0.3 fps
ALTITUDE	< 50 ft	0.3 fps
TRACK	< 50 ft	0.3 fps



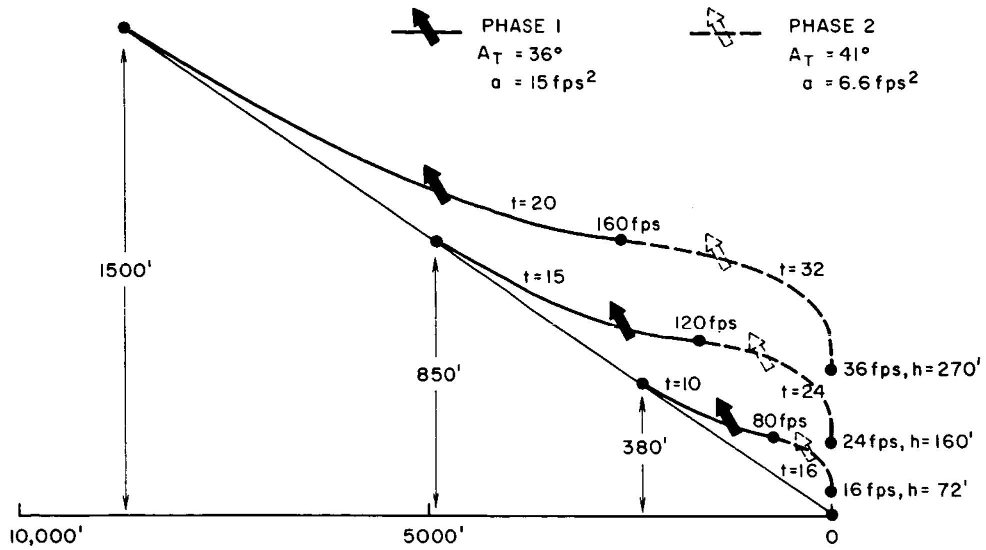
ABORT RENDEZVOUS UNCERTAINTIES (RMS) RELATIVE TO LUNAR ORBIT		
	POSITION	VELOCITY
RANGE	1.5 N.M.	0.3 fps
ALTITUDE	0.15 N.M.	0.3 fps
TRACK	0	0.3 fps

PERILUNE UNCERTAINTIES RELATIVE TO LUNAR ORBIT		
	POSITION	VELOCITY
RANGE	1000 ft	0.6 fps
ALTITUDE	1100 ft	0.6 fps
TRACK	400 ft	0

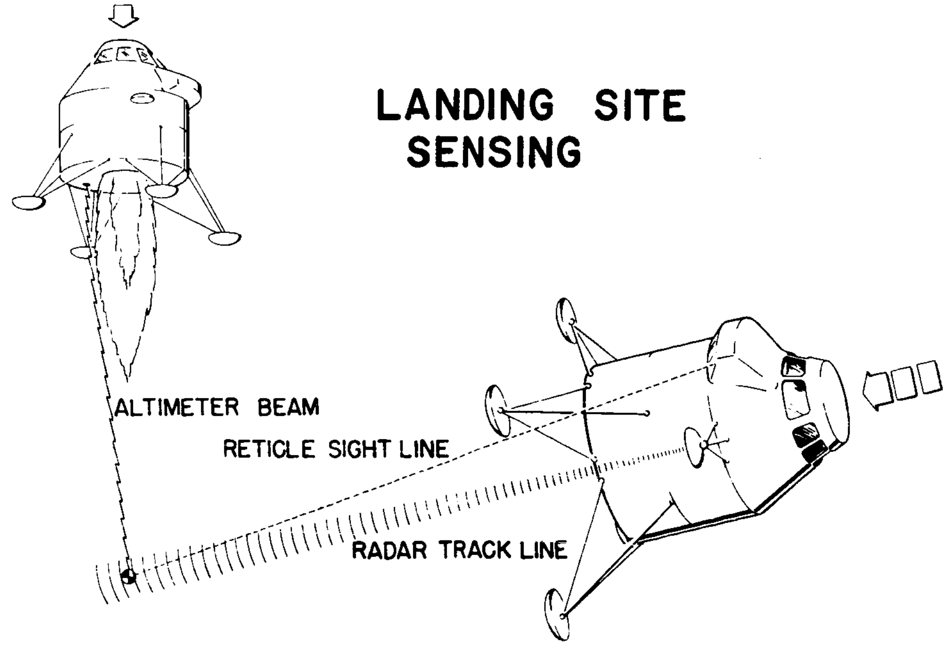
LANDING MANEUVER

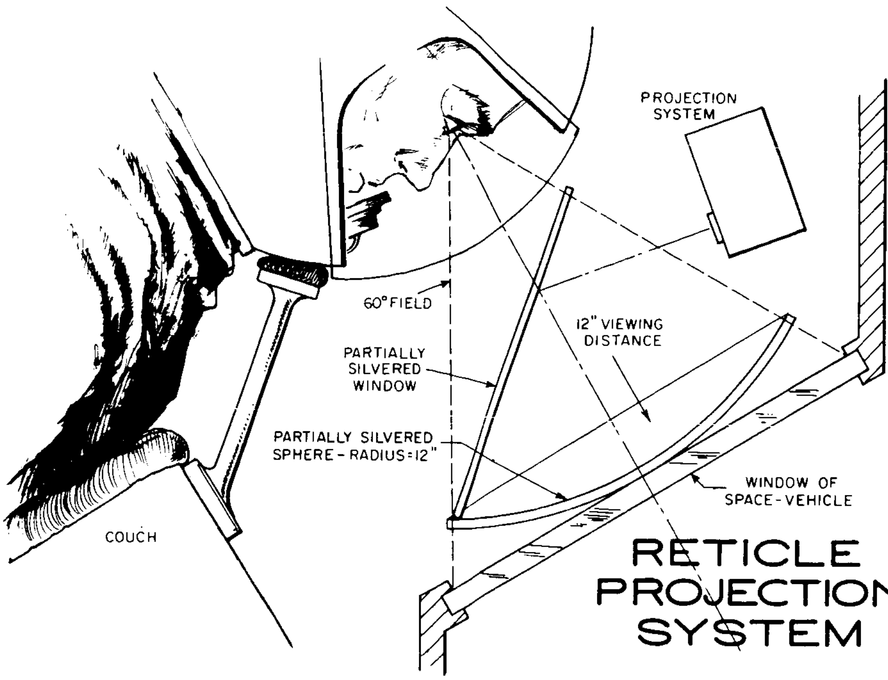


FLARE OUT TRAJECTORIES



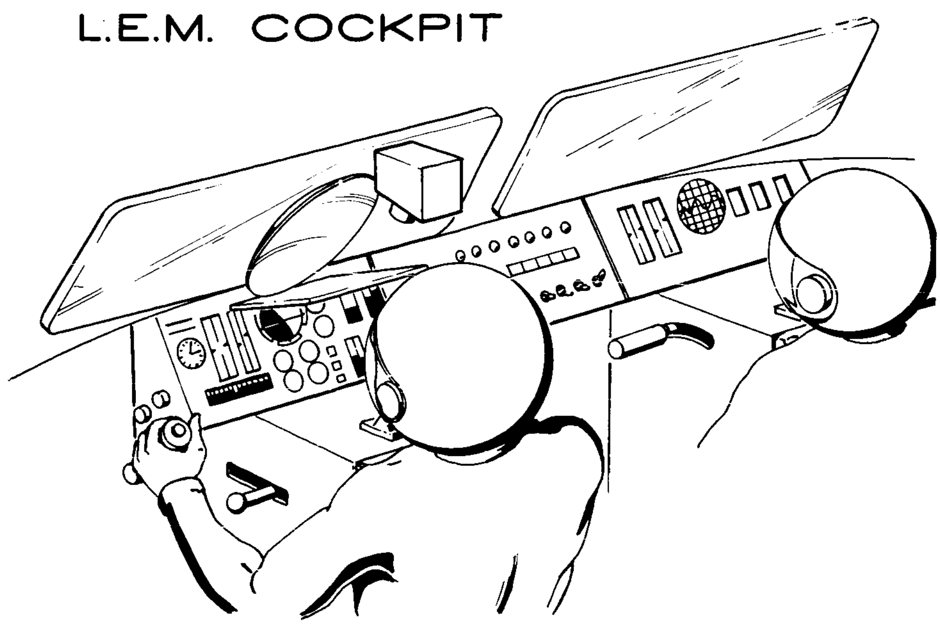
LANDING SITE SENSING

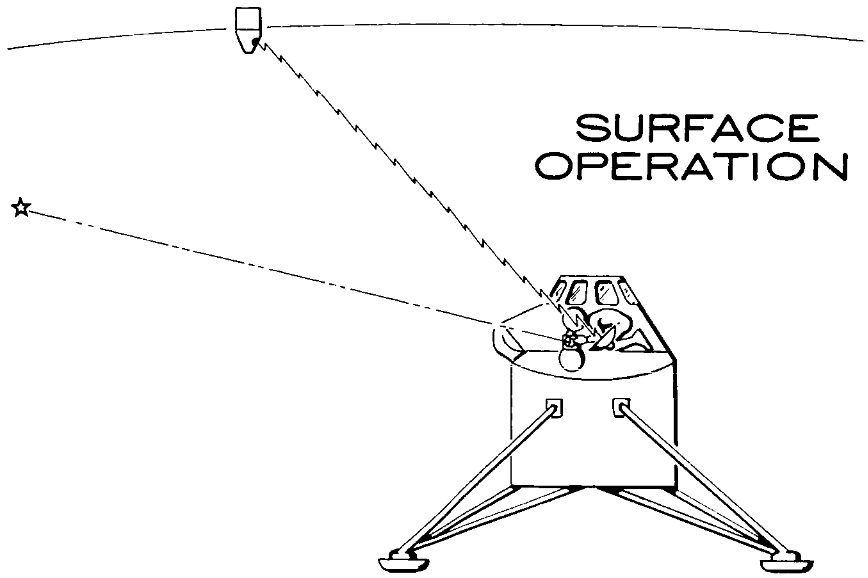




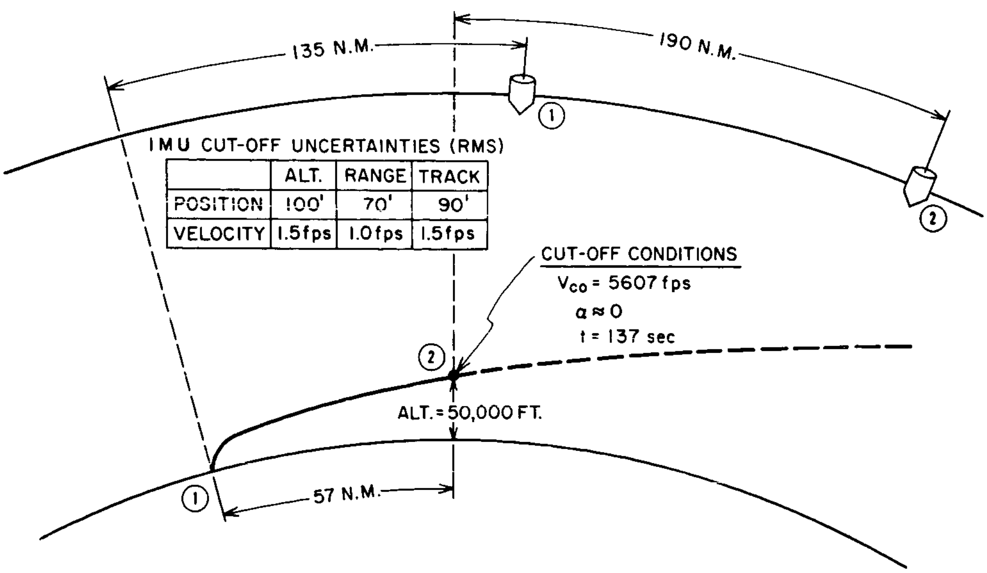
RETICLE PROJECTION SYSTEM

L.E.M. COCKPIT

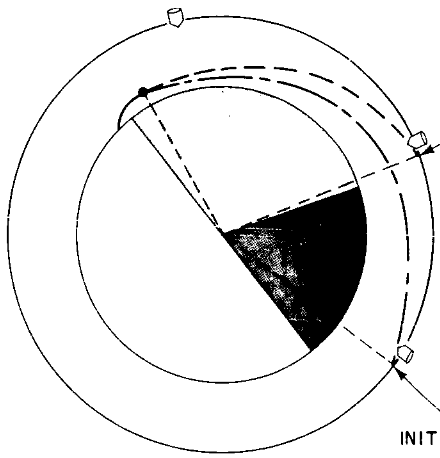


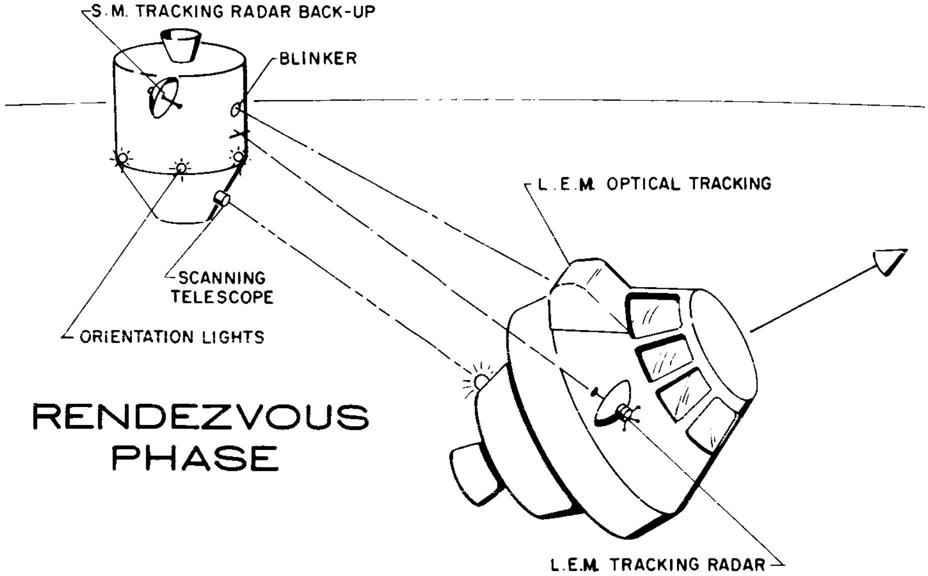


L.E.M. LAUNCH TRAJECTORY



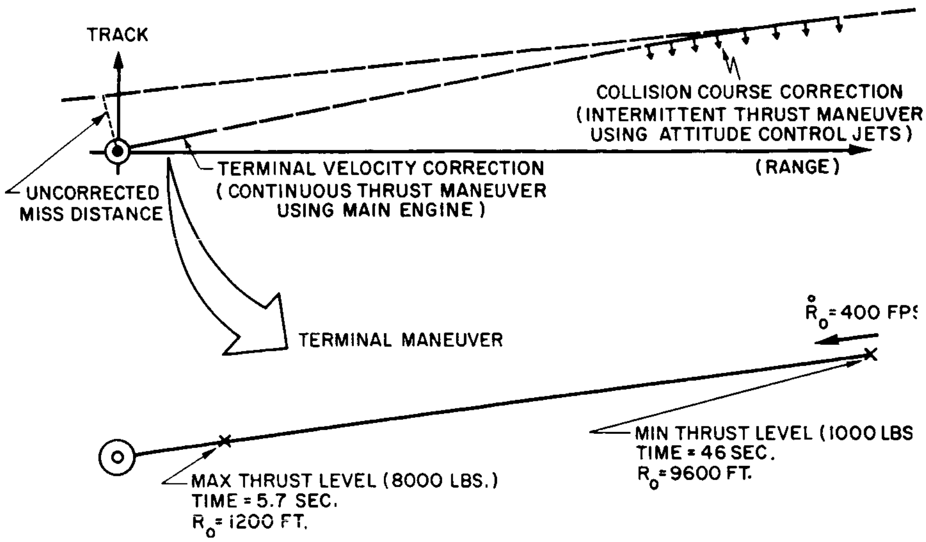
L.E.M. ASCENT TRAJECTORIES





RENDEZVOUS PHASE

RENDEZVOUS TRAJECTORY-HORIZONTAL PLANE PROJECTION



LUNAR EXCURSION MODULE CONFIGURATION, SYSTEMS AND WEIGHTS

LUNAR EXCURSION MODULE
DESIGN CRITERIA

LUNAR SURFACE MODEL:
CHOSEN AS A COMPROMISE BETWEEN LANDING SYSTEM REQUIREMENTS AND RECONNAISSANCE CAPABILITIES.

MICROMETEOROID ACTIVITY:
DESIGN FOR SPORADIC MICROMETEOROID FLUX AS GIVEN BY WHIPPLE - 1957.

RADIATION FROM MAJOR PROTON EVENTS:
PROTECTION SCHEME DESIGNED TO PERMIT OPERATIONS TO CONTINUE WITH CERTAIN LIMITATIONS ON ACTIVITIES.

SOLAR INSOLATION:
ATTENUATION OF SOLAR ENERGY FOR LUNAR SURFACE OPERATIONS PROVIDED ACCORDING TO MISSION REQUIREMENTS.

LUNAR EXCURSION MODULE
DESIGN CRITERIA (CONT'D)

PROPULSION:
LEM. PROPULSION USED FOR OPERATIONS FROM LUNAR ORBIT TO LUNAR SURFACE AND BACK TO LUNAR ORBIT RENDEZVOUS.

PROPELLANTS ARE SAME AS THOSE IN SERVICE MODULE.

SYSTEMS ARE REDUNDANT AND FAIL-SAFE WHERE ADVANTAGEOUS EXCEPT FOR MAIN THRUST CHAMBER AND INJECTOR.

GROWTH CONTINGENCY:
SIZING OF TANKAGE AND SIMILAR FACTORS ADJUSTED TO ALLOW UTILIZATION OF FULL SATURN C-5 CAPABILITY.

NON PROPULSIVE PAYLOADS CONSIDERED TO GROW 25% OVER THE PRESENT BEST ESTIMATES.

VELOCITY RESERVES PROVIDED ARE 5% IN EXCESS OF THE BEST CHARACTERISTIC VELOCITY ESTIMATES.

LUNAR EXCURSION MODULE
DESIGN CRITERIA (CONT'D)

STRUCTURAL DESIGN:

BASED ON NORMAL AND EMERGENCY MISSION PROFILES AND ENVIRONMENTS.
CABIN SHALL BE PRESSURE VESSEL PERMITTING SHIRT-SLEEVE HABITABILITY IN TRANSLUNAR FLIGHT.

LEM. INTEGRATION WITH SPACE VEHICLE:

STOWED BEHIND SERVICE MODULE FOR LAUNCH AND INJECTION.
HARD-DOCKED ON COMMAND-MODULE AIRLOCK DURING MID-COURSE.

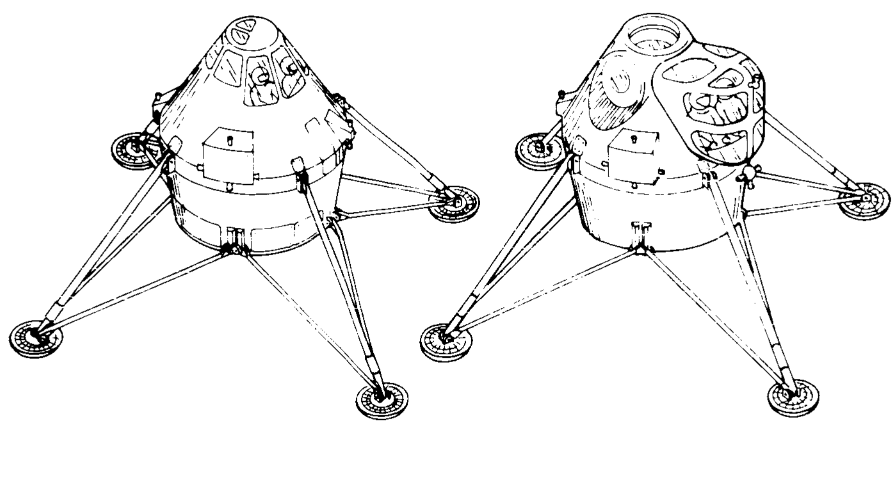
COMMUNICATION:

DIRECT COMMUNICATION LINKS BETWEEN LEM. CM. AND EARTH.
EACH MAY PERFORM RELAY FUNCTION EXCEPT AS LIMITED BY LUNAR SHIELDING.

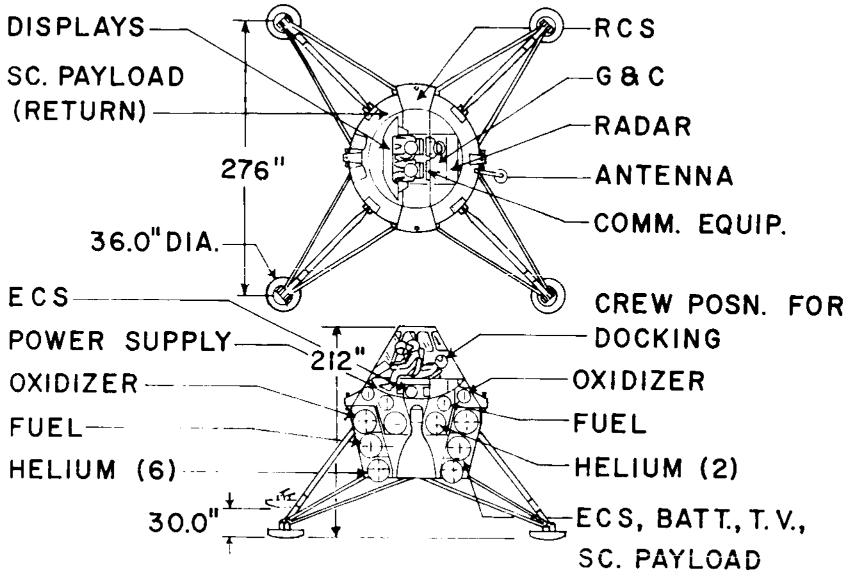
GUIDANCE:

REDUNDANT GUIDANCE AND CONTROL CAPABILITY FOR LUNAR LANDING AND RETURN TO ORBIT THROUGH INDEPENDENT OVERLAPPING MODES.

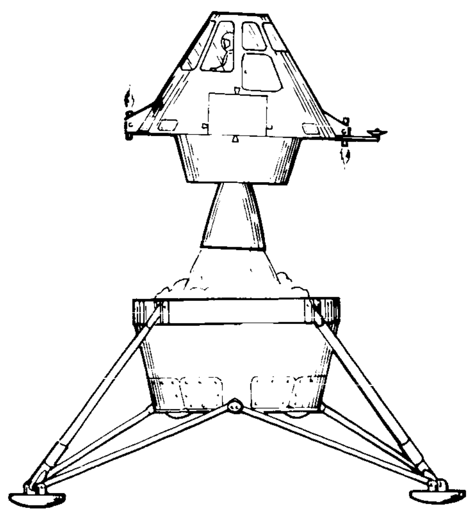
LUNAR EXCURSION MODULE
CONFIGURATION



LUNAR EXCURSION MODULE
INBOARD PROFILE AND GEOMETRY



LUNAR EXCURSION MODULE
STAGING AT LIFT-OFF OR ABORT



CREW DESCRIPTION
LUNAR EXCURSION MODULE

COMMANDER PILOT:

EXERCISES ONBOARD COMMAND.
CONTROLS SELECTION OF SYSTEM MODES.
CLOSES OUTER LOOP IN PILOTING ACTIVITY.

CO-PILOT - SYSTEMS MANAGER:

MONITORS ON BOARD SYSTEMS.
ASSISTS IN SELECTION OF SYSTEM MODES.
TAKES OVER PILOTING AS REQUIRED.

CREW EQUIPMENT
LUNAR EXCURSION MODULE

SPACE SUIT:

PERMITS PILOTING, MAINTENANCE, GENERAL MOBILITY, AND DEXTERITY.
FACE PLATE MAY BE OPEN IN CABIN ENVIRONMENT.
NORMALLY USED IN AIRLOCK AND LUNAR EXCURSION MODULE OPERATIONS.
PRIMARY EXTRAVEHICULAR PROTECTION FOR EARLY MISSION.

SUPPORT AND RESTRAINT:

NORMALLY SPINE ALIGNED WITH THRUST.
CREW MAY ALTER ORIENTATION AND GEOMETRY ACCORDING TO OPERATIONAL REQUIREMENTS.

STRUCTURAL SYSTEM
LUNAR EXCURSION MODULE

ATTACH TO ADAPTER AT MULTIPLE DISCRETE POINTS.

LANDING GEAR UTILIZES ATTACHMENT STRUCTURE.

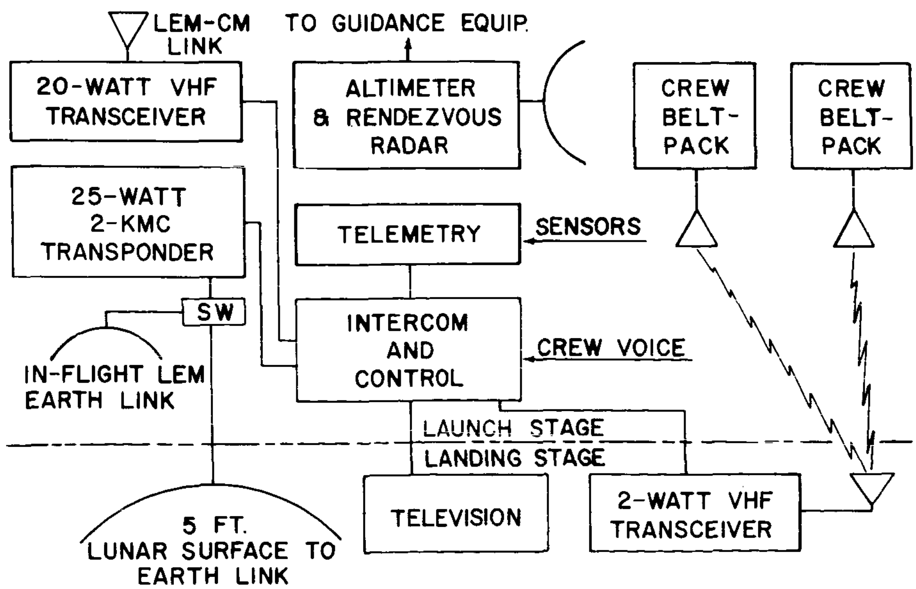
BUMPER - INSULATION COMBINATION UTILIZED FOR MICROMETEOROID ATTENUATION.

TRANSPARENT AREAS TO BE COVERED EXCEPT FOR OPERATIONAL USE.

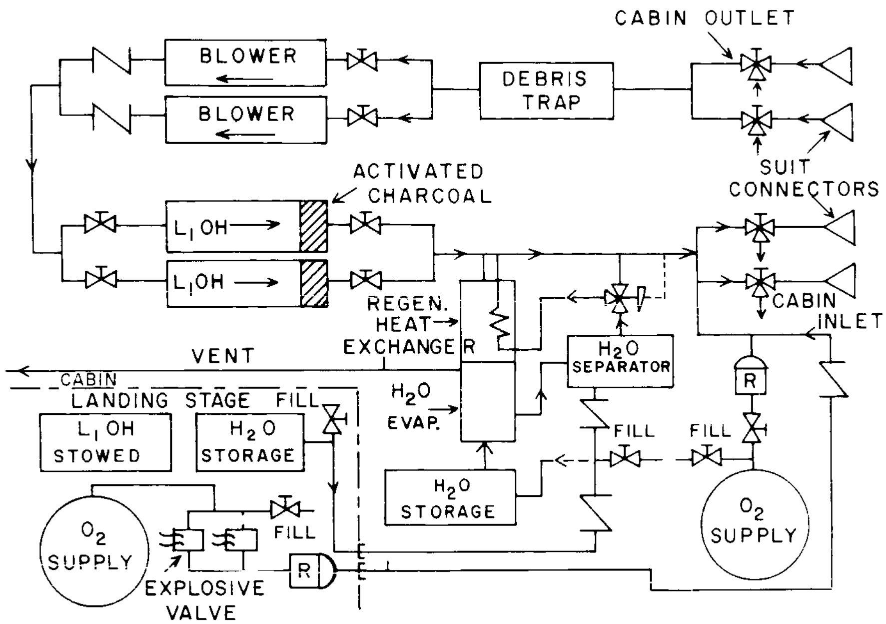
CABIN SUPPORT, DOCKING, AND THRUST STRUCTURES ARE INTEGRATED.

STAGING DISCONNECTS ARE DISCRETE AT EXISTING HARD POINTS.

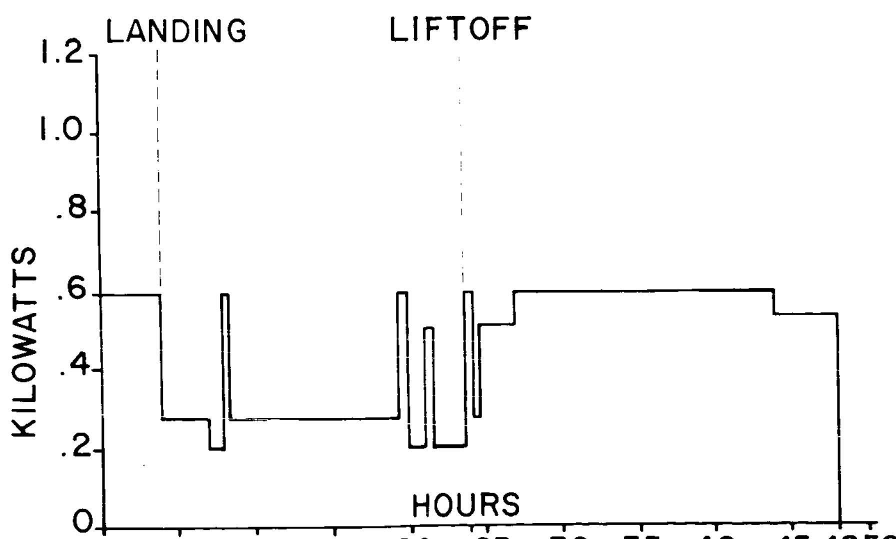
LUNAR EXCURSION MODULE
COMMUNICATIONS BLOCK DIAGRAM



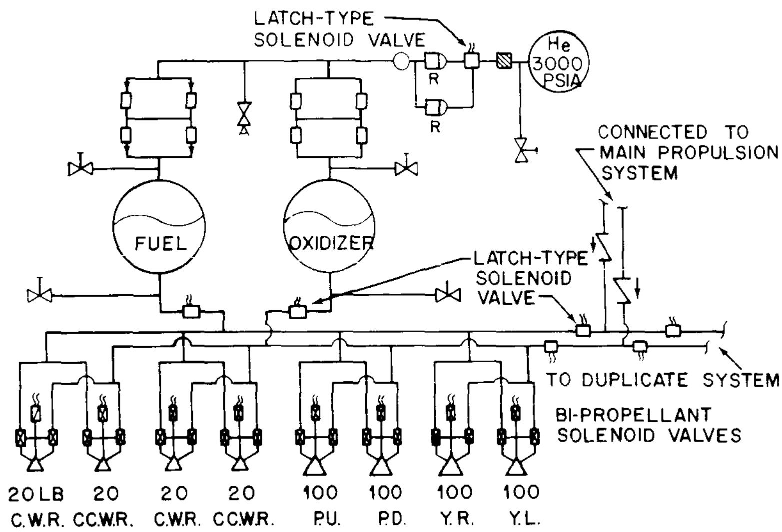
LUNAR EXCURSION MODULE ENVIRONMENTAL CONTROL



LUNAR EXCURSION MODULE ELECTRICAL SYSTEM POWER PROFILE



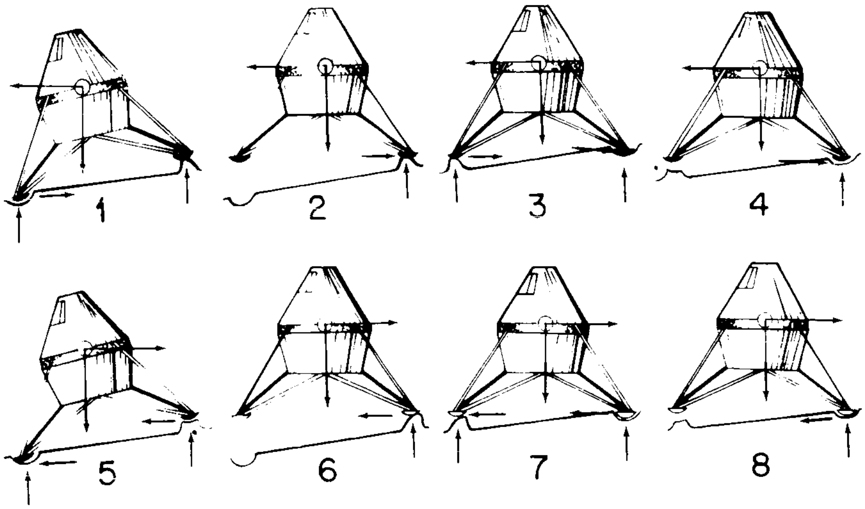
LUNAR EXCURSION MODULE
REACTION CONTROL SYSTEM



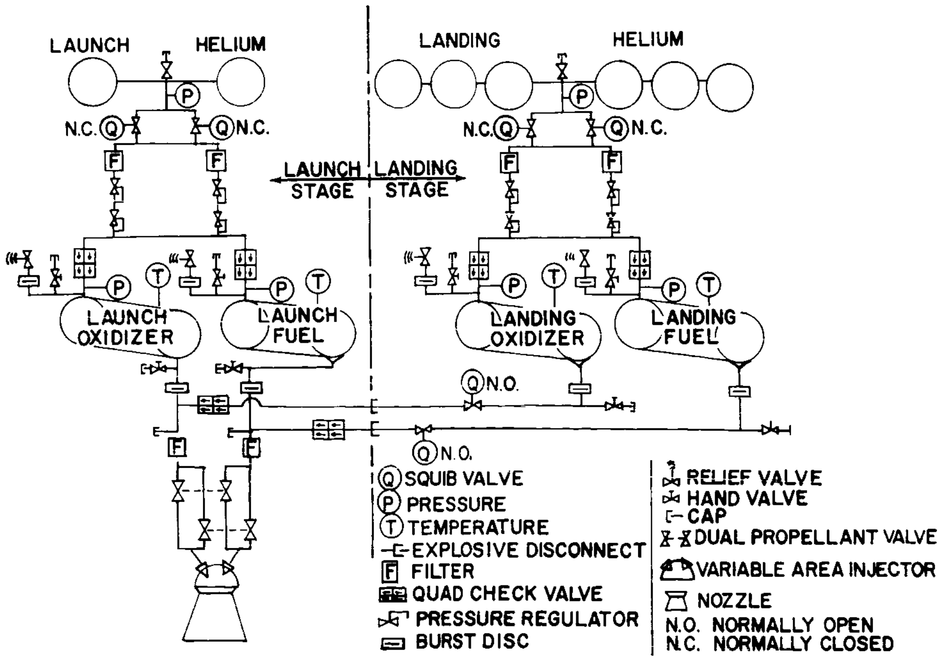
LUNAR EXCURSION MODULE
SCIENTIFIC PAYLOAD (NOMINAL MISSION)

	LANDING		LIFT OFF	
	POUNDS	CUBIC FEET	POUNDS	CUBIC FEET
RADIOACTIVITY	10	0.15		
TEMPERATURE	6	0.1		
SURFACE DETAIL	15	1.0		
ROCK SURVEY	1	.01		
COMMUNICATION	10	1.0		
SOIL ANALYSIS	10	1.0		
FRICTION	4	.15		
DENSITY SURVEY	5	.08		
CORE SAMPLE	25	1.5		
SEISMOGRAPH	40	2.0		
ATMOSPHERE	27	1.9		
GRAVITY	5	.15		
MAGNETIC FIELD	7	.4		
SAMPLE CONTAINERS	10	1.5	10.	1.5
SAMPLES			50.	
RECORDS & PHOTOGRAPHS	20	1.5	20.	1.5
FILM PROCESSING	10			
CAMERA	10	1.0		
TOTAL	215	13.44	80.	3.0

LUNAR EXCURSION MODULE
LANDING STABILITY DESIGN CONDITIONS



LUNAR EXCURSION MODULE
PROPULSION SYSTEM



NON PROPULSIVE PAYLOAD FOR LUNAR EXCURSION MODULE

DESCRIPTION	LANDING Weight (lbs.)	LIFTOFF Weight (lbs.)
CREW and EQUIPMENT	455	455
STRUCTURE	396	396
GUIDANCE and CONTROL	287	287
COMMUNICATIONS	193	133
ENVIRONMENTAL CONTROL SYSTEM	468	302
ELECTRICAL POWER SYSTEM	463	197
REACTION CONTROL SYSTEM	150	150
INSTRUMENT PANEL	80	80
SCIENTIFIC PAYLOAD	215	80
TOTAL PAYLOAD WEIGHT (No Growth)	2707	2080
CONTINGENCY (25 percent)	677	520
TOTAL-PAYLOAD WEIGHT (With Growth)	3384	2600

LUNAR EXCURSION MODULE DESIGN VELOCITY INCREMENTS

PHASE OF MISSION	VELOCITY FT/SEC	VELOCITY +5% FT/SEC
CIRCULAR TO ELLIPTIC ORBIT	120	
BRAKE TO ZERO-NEAR SURFACE	5924	
HOVER, TRANSLATION, TOUCHDOWN	800	
LEM LANDING STAGE	6844	7186
ASCEND TO ELLIPTIC ORBIT (T/W = .4)	6000	
ELLIPTIC TO CIRCULAR ORBIT	120	
RENDEZVOUS IN LUNAR ORBIT	600	
LEM LAUNCH STAGE	6720	7056

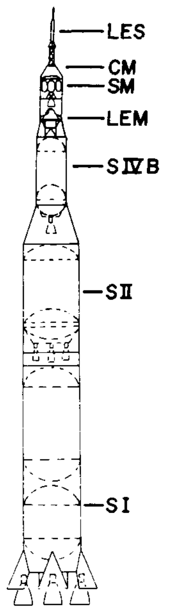
LUNAR EXCURSION MODULE
SUMMARY WEIGHT STATEMENT (25% GROWTH)

DESCRIPTION	SEPARATION	LANDING	LIFTOFF	BURNOUT
PAYLOAD (25% GROWTH)	2600	2600	2600	2600
LAUNCH INERT PROPULSION	850	850	850	850
LAUNCH PROPELLANT	3625	3625	3625	
LANDING INERT PROPULSION	1520	1520		
LANDING PROPELLANT	10473			
LANDING GEAR	414	414		
LANDING AIDS	22			
PAYLOAD LEFT ON LUNAR SURFACE	784	784		
TOTAL WEIGHT	20288	9793	7075	3450

MISSION WEIGHT HISTORY

DESCRIPTION	NOMINAL	25% GROWTH
LAUNCH ESCAPE SYSTEM (4%)	250	250
COMMAND MODULE (TOTAL)	8,500	10,625
SERVICE MODULE	36,004	41,042
ADAPTER	1,450	1,450
LEM. (LESS CREW)	17,302	19,818
EARTH ESCAPE	63,506	73,185
IN LUNAR ORBIT	42,053	48,626
LEM. SEPARATION	17,772	20,288
LEM. LANDING	8,574	9,793
TOTAL LEFT ON MOON	2,561	2,718
PAYLOAD LEFT ON MOON	627	784
LEM. LIFT OFF	6,013	7,075
LEM. BURNOUT	2,930	3,450
ORBIT-DOCKED	27,681	32,258
PRIOR TO TRANS EARTH	24,751	28,808
PRIOR TO REENTRY	16,684	19,434

SATURN C-5 LAUNCH VEHICLE PERFORMANCE MARGINS



SAT. C-5
DESIGN FOR ESCAPE RESTART IN ORBIT

CM/SM+ADAPTER +LES EFFECTIVE WT	MAX 54,000 NOM 46,500	
LUNAR EXCURSION MODULE	MAX 20,000 NOM 17,500	
USABLE PROPELLANT (INCLUDES FPR 20,000)	216,000*	S IVB
BURN-OUT WEIGHT	25,000*	S IVB
USABLE PROPELLANT	872,000*	S II
BURN-OUT WEIGHT	86,000*	S II
USABLE PROPELLANT	4,320,000*	S I
BURN-OUT WEIGHT	403,000*	S I

MIN GUARANTEED PAYLOAD	90,000
MAX REQ	74,000
NOM REQ	64,000
% MIN MARGIN	22
% NOM MARGIN	40

C-5 STAGED IN ORBIT

MIN GUARANTEED	80,000
MAX REQUIRED	74,000
% MIN MARGIN	8
% NOM MARGIN	25

LUNAR EXCURSION MODULE
PROPULSION

FLIGHT RELIABILITY HISTORY OF TITAN, ATLAS, THOR, REDSTONE, JUPITER

COMPONENT OR SUBSYSTEM	% TOTAL FAILURES
TURBOPUMP	15
ENGINE VALVES AND REGULATORS	15
THRUST CHAMBERS (ROUGH COMBUSTION)	3
TANKS AND LINES	6
PROPELLANT SLOSH	3
PROPELLANT UTILIZATION	5
PRESSURIZATION SYSTEMS	8
THRUST VECTOR CONTROL & HYDRAULICS	6
ELECTRICAL POWER & DISTRIBUTION	14
FLIGHT CONTROLS	12
GUIDANCE	9
STRUCTURES	4

HIGH RELIABILITY REQUIRES

- OPERATION UNDER AN EXTREME RANGE OF OFF - DESIGN CONDITIONS AND ENVIRONMENT.
- SYSTEM OPERATION INDEPENDENT OF SINGLE COMPONENT FAILURES.
- REDUNDANT COMPONENTS LINKED SUCH THAT ADDITIONAL COMPONENTS DO NOT HAVE TO FUNCTION TO SENSE AND INITIATE REDUNDANT OPERATIONAL MODE.
- MINIMUM OF COMPONENTS, LINES, FITTINGS, CIRCUITRY.
- SIMPLE CHECK OUT AND OPERATIONAL TEST.

REDUNDANT ENGINES

ADVANTAGES	DISADVANTAGES
• REDUNDANT VALVES AND VALVE ACTUATORS.	• MALFUNCTION DETECTION AND SWITCHING SYSTEM REQUIRED FOR PROPELLANTS AND THRUST VECTOR CONTROL SYSTEM.
• REDUNDANT THRUST CHAMBERS.	• CATASTROPHIC MALFUNCTION PROBABILITY INCREASED.
	• COMPLICATES CONTROL ELECTRONICS.
• REDUNDANT THRUST-VECTOR CONTROL.	• PROPELLANT FEED LINES, VALVES, FITTINGS INCREASE POTENTIAL LEAK POINTS AND HUMAN ERROR POINTS.
	• PROPELLANT DEPLETION DESIGN COMPLICATED DUE TO MULTIPLE ATTITUDE AT DEPLETION.
	• CREW VISIBILITY AND MANUAL CONTROL COMPLICATED.
	• STABILITY AND CONTROL COMPLICATED BY ENGINE FAILURE.

SINGLE ENGINE WITH REDUNDANT VALVES & THRUST VECTOR CONTROL

ADVANTAGES	DISADVANTAGES
• REDUNDANT VALVES & ACTUATORS.	• THRUST CHAMBER NOT REDUNDANT
• REDUNDANT THRUST VECTOR CONTROL.	
• NO MALFUNCTION DETECTION & SWITCHING CIRCUITS.	
• LESS PROBABILITY OF CATASTROPHIC MALFUNCTION.	
• SINGLE ATTITUDE FOR LANDING.	
• NO COMPLEXITIES ADDED TO ANY OTHER SYSTEM.	

REDUNDANCY IN ONE OF THE MOST RELIABLE SYSTEMS OF THE VEHICLE HAS BEEN SACRIFICED TO AVOID COMPLICATIONS OF RELATIVELY UNRELIABLE ELECTRICAL NETWORKS AND FLIGHT CONTROLS

SINGLE THRUST-CHAMBER SPECIAL DESIGN FEATURES

- LARGE FLOW PASSAGE; SCREENED INJECTOR MANIFOLDS.
- BAFFLED COMBUSTION CHAMBER STABLE FOR ANY INJECTOR FLOW OR PRESSURE ADEQUATE FOR MISSION T/W.
- COMBUSTION CHAMBER DESIGN TOLERABLE TO ANY MALFORMED INJECTOR PATTERN OR OFF-DESIGN O/F RATIO ALLOWING MISSION COMPLETION.
- EXTREMELY RUGGED MECHANICAL CONSTRUCTION INSENSITIVE TO TEMPERATURE VARIATION, METEORITES, OPERATIONAL HAZARDS.
- ABLATIVE CHAMBER DESIGN.

CHOICE OF PROPELLANTS

LAUNCH-VEHICLE PERFORMANCE & PAYLOAD REQUIREMENT ALLOWS UNCOMPROMIZED CHOICE FOR RELIABILITY & OPERATIONAL CONSIDERATIONS.

CHARACTERISTICS OF MON/MMH -

- EASY TROTTLING - HYPERGOLIC STARTS - SIMPLE SYSTEM.
- LOW THERMAL DISTORTION OF MECHANICAL PARTS.
- COUNTDOWN AND CHECKOUT PROBLEMS MINIMIZED.
- SMALL VEHICLE HAS OPERATIONAL ADVANTAGES FOR:
  - (A) VISIBILITY & MANEUVERABILITY DURING LANDING
  - (B) CREW TRAINING OPERATIONS & SYSTEMS DEVELOPMENT
  - (C) PACKAGING IN LAUNCH VEHICLE

CONSIDERATIONS FOR STAGED VS PARTIAL-STAGED LEM PROPULSION

ADVANTAGES	DISADVANTAGES
STAGED	
• SEPARATE WELL-PROTECTED ABORT ENGINE NOT SUBJECTED TO MECHANICAL HAZARDS OF LANDING.	• LONGER VEHICLE REQUIRES MORE LANDING LEGS AND MORE C-5 ADAPTER LENGTH.
• ABORT ENGINE SIMPLER, NO THROTTLING REQUIREMENTS.	• ENGINE-CONTROL SIGNAL TRANSMITTED ACROSS STAGING DISCONNECT.
PARTIAL STAGED	
• COMPACT, SHORT VEHICLE, LESS LANDING LEGS, SHORT C-5 ADAPTER.	• NO SEPARATE ABORT ENGINE.
• SOME MANEUVERABILITY ADVANTAGE.	• MAIN PROPELLANT LINE DISCONNECT REQUIRED.
UNSTAGED	
• SOME MANEUVERABILITY ADVANTAGE.	• NO SEPARATE ABORT ENGINE.
• COMPLETELY INTEGRATED PACKAGE, NO STAGING DISCONNECTS.	• CAN NOT PERFORM MISSION WITH SAT C-5 UNLESS HIGH ENERGY PROPELLANTS ARE USED.
	• MAY HAVE PROPELLANT DYNAMICS PROBLEMS DURING LANDING MANEUVER.
	• ALL SYSTEMS ACTIVATED DURING FULL LEM MISSION.

SPACECRAFT INTEGRATION

SYSTEM DESIGN CRITERIA

LUNAR EXCURSION MODULE

SYSTEMS NOT ACTIVATED UNTIL LUNAR APPROACH

COMMAND MODULE

SUPPLIES ALL LIFE SUPPORT, POWER, ENVIRONMENTAL,
GUIDANCE, CONTROL & COMMUNICATIONS
UNTIL LUNAR ORBIT ESTABLISHED

REDUCTION IN C/M & S/M WEIGHT

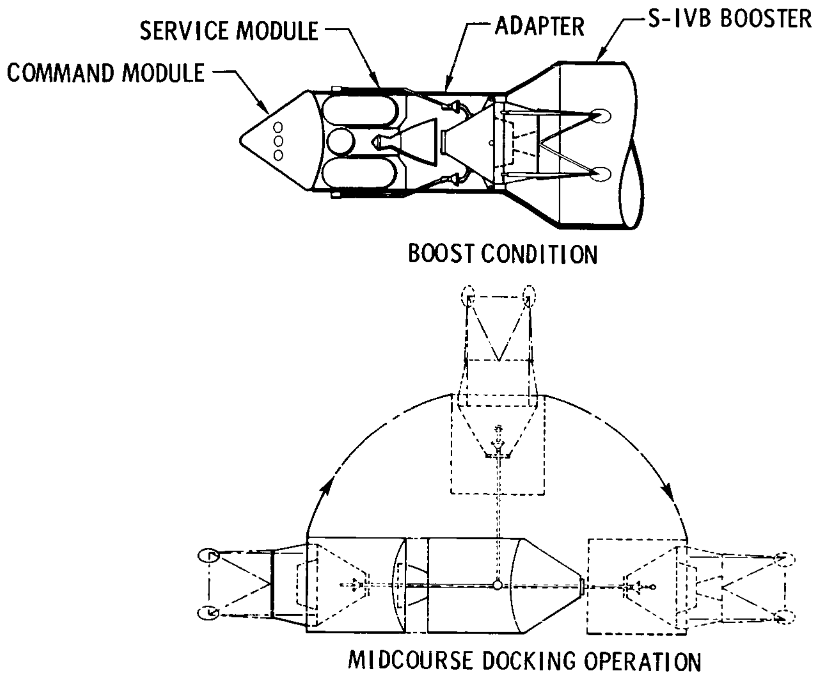
CRITERIA

8-1/2-DAYS EQUIPMENT OPERATION (2-1/2 DAYS IN LUNAR ORBIT)
20-1/2 MAN-DAYS OF CREW LIFE SUPPORT
(PLUS 9 MAN-DAYS EARTH RECOVERY)

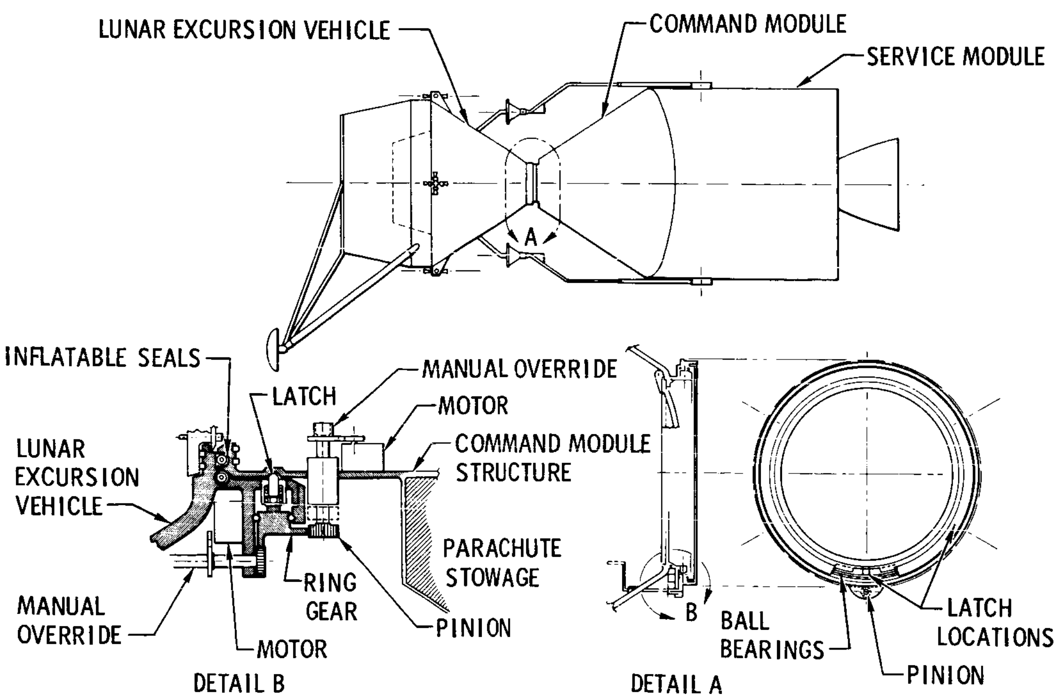
COMMAND MODULE EQUIPMENT	WEIGHT CHANGE*
FOOD & CONTAINERS	46 LB
CO_2 ABSORBERS	50 LB
SERVICE MODULE EQUIPMENT	
NITROGEN & CONTAINERS	23 LB
OXYGEN & CONTAINERS	67 LB
FUEL-CELL REACTANTS	250 LB
REACTION CONTROL	21 LB
HEAT-PUMP SYSTEM	43 LB
	500 LB

*WEIGHT CHANGE FROM MARCH 9 STATUS

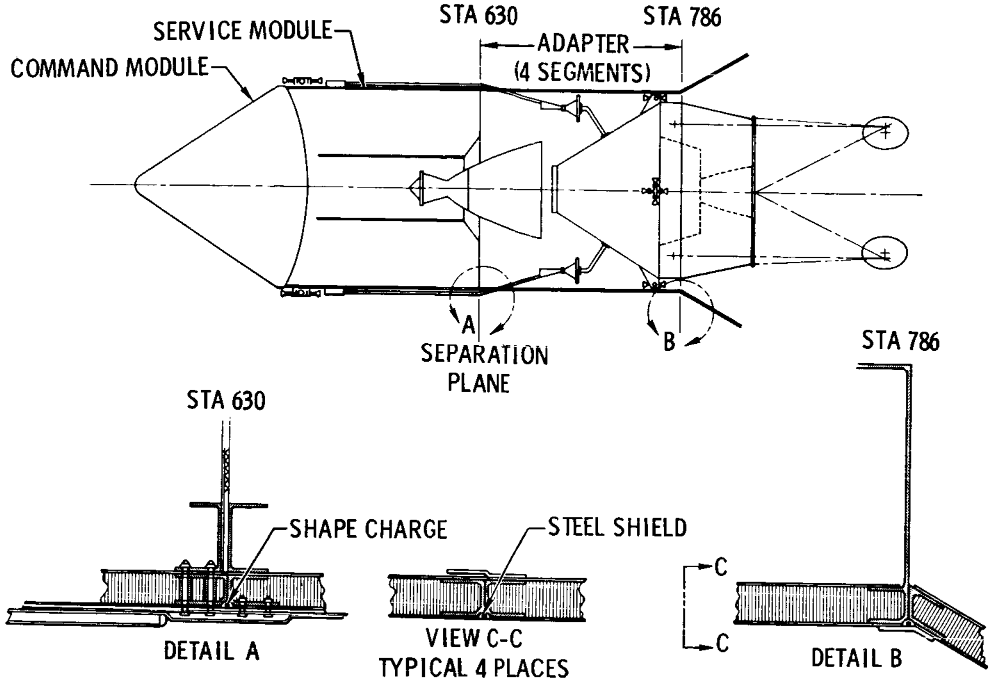
SHUTTLE TRANSFER SYSTEM



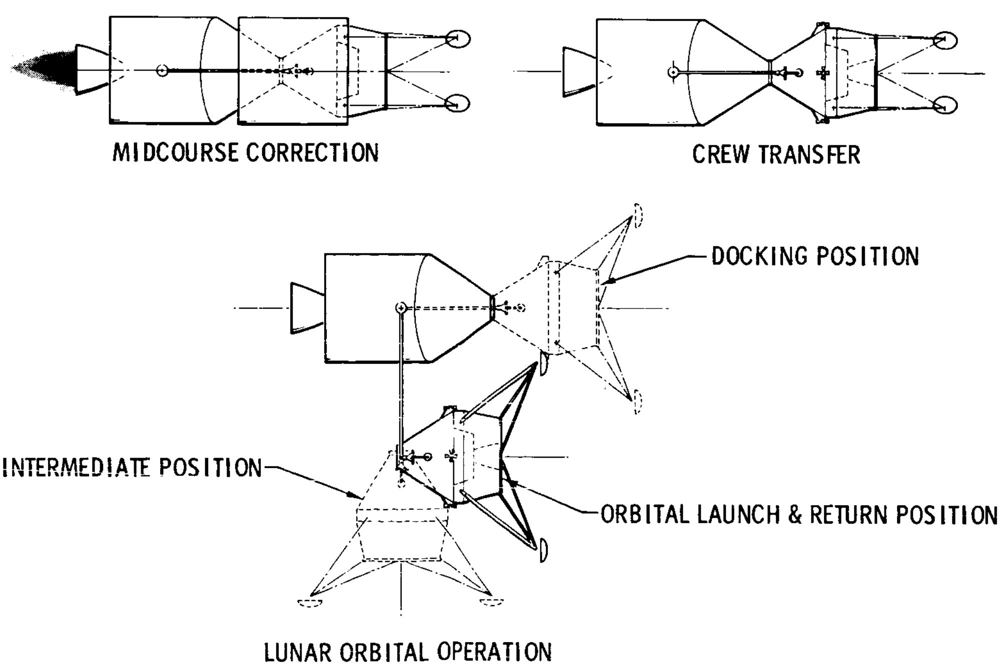
AIRLOCK ATTACHMENT



ADAPTER ATTACHMENT & SEPARATION



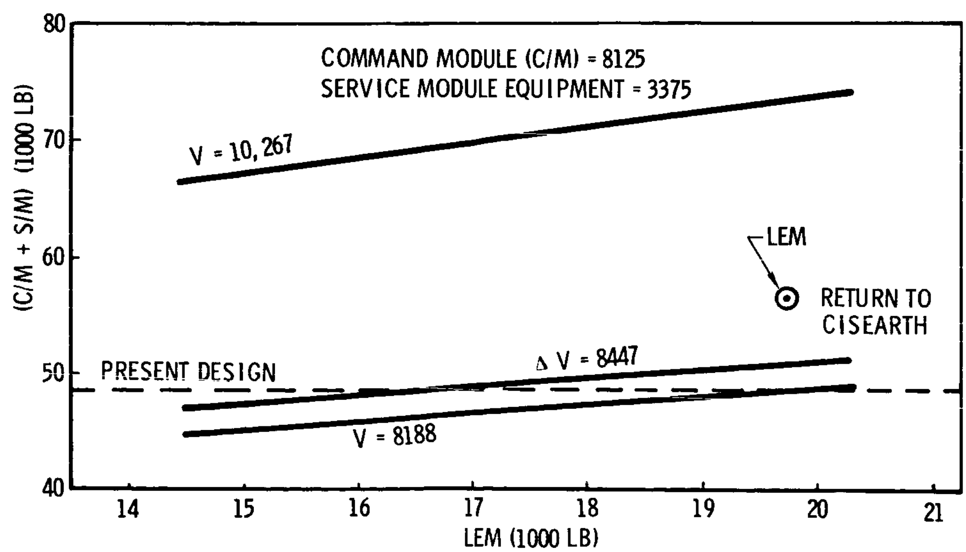
SHUTTLE TRANSFER SYSTEM



LAUNCH & RETURN REQUIREMENTS

	LUNAR ORBITAL RENDEZVOUS			DIRECT LUNAR LANDING MISSION -RETURN-
	MAXIMUM	POSSIBLE DESIGN	MINIMUM	
	FREE RETURN TO POINT LANDING 100% MONTH	TRANSLUNAR EQUATORIAL 100% MONTH	ONCE A MONTH	
<u>TRANSLUNAR</u>				
MIDCOURSE	500	500	500	
ORBIT INJECTION	3,281	3,281	3,167	
ORBIT TRANSFER -EQUATORIAL	1,770	—	—	
CONTROL TOLERANCE 3%	167	113	110	
	5,718	3,894	3,777	
<u>TRANSEARTH</u>				
LUNAR BOOST	—	—	—	5,980
ORBIT EJECTION	3,916	3,916	3,780	3,355
MIDCOURSE	500	500	500	500
CONTROL TOLERANCE 3%	133	133	128	500
	4,549	4,549	4,408	
TOTAL	10,267	8,443	8,185	10,335

SERVICE MODULE (S/M) WEIGHT VARIATION



SYSTEM FLEXIBILITY VS INJECTION WT

LEM + ADAPTER = 22,000 LB

LAUNCH FLEXIBILITY	INJECTION WEIGHT
FREE RETURN POINT LANDING 100% MO	94,000 LB
TRANSLUNAR EQUATORIAL 100% MO	70,000 LB
ONCE A MONTH	68,000 LB

EFFECTS OF VARIATIONS IN C/M & LEM WTS ON S/M WTS

$$\frac{\delta \text{ S/M}}{\delta \text{ C/M}} = 3.3 \text{ LB/LB}$$

$$\frac{\delta \text{ S/M}}{\delta \text{ LEM}} = 0.7 \text{ LB/LB}$$

LEM = 20,000 LBS

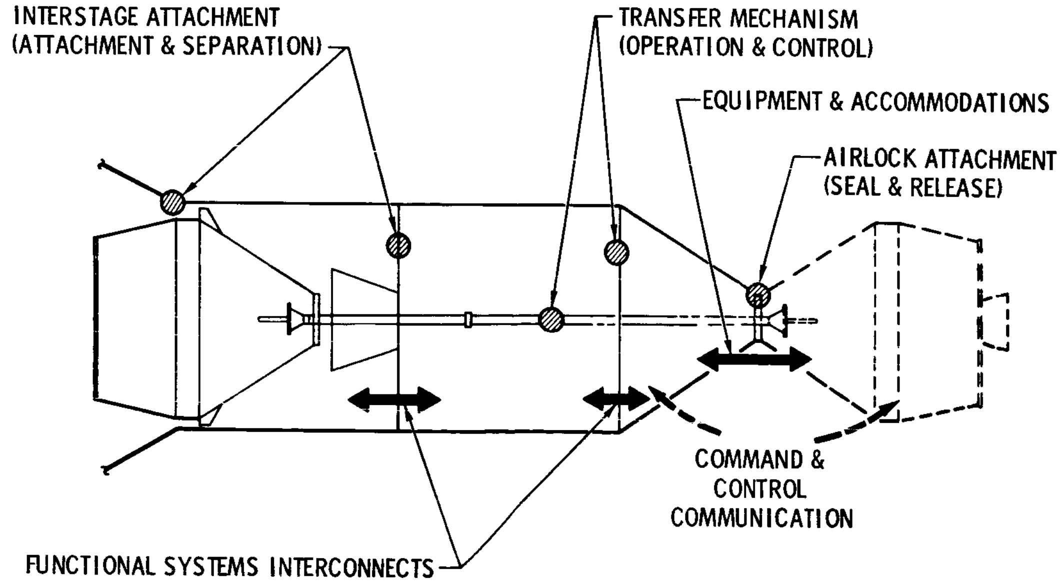
SPACECRAFT WEIGHTS — EFFECT OF EXTENDING MISSION OVER 8 DAYS

$$\frac{\delta\ \text{POWER SYSTEM}}{\delta\ \text{TIME}} = 47\ \text{LB/DAY}$$

$$\frac{\delta\ \text{LIFE SUPPORT SYSTEM}}{\delta\ \text{TIME}} = 15\ \text{LB/MAN-DAY}$$

PRIMARY INTERFACE REQUIREMENTS

COMMAND MODULE - SERVICE MODULE - LUNAR EXCURSION MODULE



REVISIONS TO APOLLO SPACECRAFT

CONFIGURATIONS

- COMPATIBLE DOCKING PROVISIONS
- PROVIDE SYSTEM INTERCONNECTORS
- LOADS ON AIRLOCK
- PROVIDE EARTH LAUNCH STOWAGE

REVISIONS TO APOLLO SPACECRAFT (CONT)

COMMUNICATIONS SYSTEMS

- ADD: 310-MC & 270-MC POWER AMPS & TRANSMITTERS

  VHF OMNI-ANTENNA

  RADAR TRANSPONDER

  CHECKOUT EQUIPMENT

  (WT—37 LB—PEAK POWER: 99 W)

REVISIONS TO APOLLO SPACECRAFT (CONT)

POWER SYSTEMS

- REMOVE LUNAR LANDING OPERATIONAL LOADS
- CHANGE EQUIPMENT OPERATION FROM 14 DAYS TO 8-1/2 DAYS
- SUPPLY POWER FOR LEM IN-FLIGHT CHECKOUT

  TOTAL ENERGY APPROXIMATELY - 500 W HR

  PEAK POWER APPROXIMATELY - 750 W

REVISIONS TO APOLLO SPACECRAFT (CONT)

ENVIRONMENTAL CONTROL

- REMOVE LUNAR LANDING HEAT LOADS

CREW PROVISIONS

- REDUCE MISSION PROVISIONS TO 20-1/2 MAN-DAYS (FROM 42 MAN-DAYS)

GUIDANCE & NAVIGATION

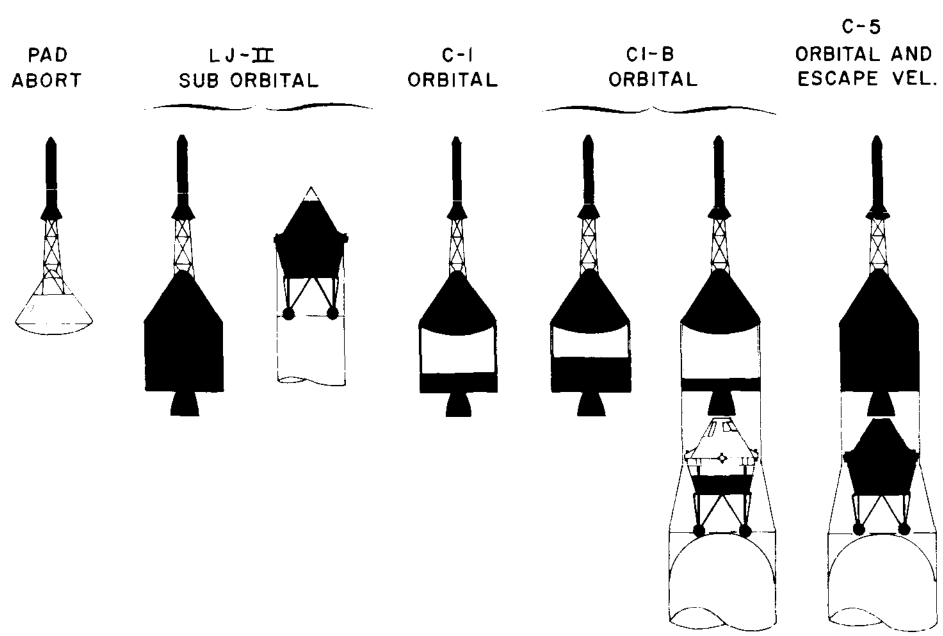
- SUPPLY - INERTIAL SYSTEM ALINEMENT DATA
- - ORBITAL EPHEMERIS DATA & TIME REFERENCE
- ADD - LIGHT BEACON (200 W), RADAR BEACON TRANSPONDER

MISSION DEVELOPMENT PLAN

APOLLO MISSION DEVELOPMENT PLAN

SPACECRAFT COMPONENT	FLIGHT RESUME	LAUNCH VEHICLE
LAUNCH ESCAPE SYSTEM	SUB-ORBITAL	OFF-PAD LITTLE JOE II
COMMAND MODULE	SUB-ORBITAL	LITTLE JOE II C-5
COMMAND & SERVICE MODULE	SUB-ORBITAL ORBITAL	LITTLE JOE II C-1 C-1B
LUNAR EXCURSION MODULE	SUB-ORBITAL	LITTLE JOE II
COMPLETE SPACECRAFT	ORBITAL LUNAR	C-1B C-5

SPACECRAFT CONFIGURATIONS TO BE TESTED



APOLLO FLIGHT SCHEDULE
LUNAR RENDEZVOUS TECHNIQUE